

# **STUDIES IN A FILIPENDULA ULMARIA L. MEADOW ECOSYSTEM AND THE EFFECTS OF CADMIUM**

**I. PLANT BIOMASS, PRIMARY PRODUCTION  
AND LITTER DISAPPEARANCE**

**II. CONCENTRATION AND DISTRIBUTION OF  
CADMIUM IN PLANT BIOMASS AND SOIL**

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STUDIES IN A FILIPENDULA ULMARIA L. MEADOW ECOSYSTEM  
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## 1 INTRODUCTION

Cadmium and its compounds are used in several manufacturing processes. These processes, and the use and destruction of their products release cadmium to the environment as does the use of fossil fuels, phosphate fertilizers and zinc alloys. The concentration of the metal in the environment has increased rapidly during recent decades.

Even small amounts of cadmium are highly toxic for most, perhaps all organisms, and this realisation was the spur, during the 1970's, to several studies of the metal and its effects not only on man and animals but also on plants.

The most usual subjects of such studies have been crop plants or vegetables, grown in pots with soil or nutrient solution (among others Page et al. 1972, Haghiri 1973, Huang et al. 1974, Carlson et al. 1975, Collins et al. 1976, Rothenberger and Galitz 1977, Davis et al. 1978). Much concern has also been expressed about cadmium enriched sewage sludge (among others Bingham et al. 1975, Hinesly et al. 1976, Mahler et al. 1978) but sewage sludge is usually rich in other heavy metals too, so the specific effects of cadmium are difficult to disentangle. It seems clear that the tolerance of plants to cadmium may vary considerably not only between species and species varieties (Page et al. 1972, Haghiri 1973, Turner 1973, Boggess et al. 1978) but also between individuals of the same species, probably because the uptake of cadmium is dependent on the growth conditions (John et al. 1972, Haghiri 1974, Miller et al. 1976). Despite all this work little is known about the effects of cadmium on wild plant species, especially under natural conditions. Because of the increasing rate of cadmium dispersal into the environment, such information would be of greatest interest. Here I report a study of the ecological effects of cadmium in a natural ecosystem, a tall herb meadow with dominant Filipendula ulmaria.

Tall herb meadows are characterizised by a high net primary production and a fairly rapid decomposition of litter and circulation of mineral elements. The simple structure of this particular ecosystem, with one dominating species and yearly renewal of aboveground biomass, is a great practical advantage, but the almost total lack of previous work on such a system is a disadvantage. To understand the ecological role of cadmium, it was necessary therefore to make a detailed study, with and without added cadmium, of the functions of the ecosystem. The detailed aims of this work were to study:

- the seasonal development and vigour of the plant (Filipendula ulmaria)
- the seasonal changes and distribution of above- and below-ground biomass
- the above- and belowground annual net primary production
- the rate of formation and disappearance of litter.

## 2 STUDY AREA

The study was carried out near Lake Egeside, ca.18 km S of Kristianstad, South Sweden. The water level has been artificially lowered and the lake is almost overgrown. A forest, composed mainly of alder (Alnus glutinosa L.) intermingled with birch (Betula verrucosa Ehrh.), pine (Pinus sylvestris L.) and shrubs such as Salix spp., Prunus padus L., Viburnum opulus L. and Euonymus europaeus L. is invading the 'lake'.

The study area, a tall herb meadow, lies at the southern border of the forest (55°52'N, 14°11'E and 4-5 m above sea level).

## 3 VEGETATION AND SOIL

The vegetation of the study area is uniform in composition and contains no trees or shrubs. The meadow-sweet (Filipendula ulmaria L.) (hereafter named Filipendula only) dominates the area totally. Other more abundant herbs, interspersed in the



field layer are Vicia cracca L., Galium aparine L., Galeopsis tetrahit L. and Urtica dioica L.. The last is especially common at the borders of the area. Graminids are scarce. Only a few large and high tussocks of sedge (Carex caespitosa L.) break the dense field layer. A bottom layer is almost lacking and the few moss species of the area occur in very small patches, mainly on dead branches, which have fallen from trees and shrubs in the surroundings.

The area is almost flat with only a slight slope towards the east. The soil is a moist peaty mull with 10-20% clay, 40-70% organic matter and a high cation exchange capacity (Tab. 1). At the soil surface, pH is about neutral and the amount of exchangeable Ca is more than 16 mg/g dry weight of the soil.

For most of the year, the ground water table is in the top 20 cm of the soil profile. Only during the summer months does the level fall to 40-50 cm below the soil surface. A more detailed description of the physical and chemical properties of the soil will be given in another paper (Balsberg in prep.).

#### 4 CLIMATE AND METEOROLOGICAL CONDITIONS DURING THE FIELD STUDY

The area belongs to the warm temperate climatic zone in the Köppen - Geiger system (Strahler, 1973). The duration of the growth period, defined as the period with a daily temperature above +3 °C is 230 days, corresponding to the period 1 April - 20 November (Atlas över Sverige 1953-1971: 28).

No continuous climatic measurements were made at the study area, but such measurements are available from a meteorological station at Kristianstad. The study area is 3.5 km from the sea; the meteorological station is 20 km inland.

The annual mean temperature and precipitation for the years 1931-1960 were 7.5 °C and 577 mm. January was the coldest

| Soil depth<br>(cm) | Clay<br>(% dry<br>weight) | Organic<br>matter<br>(% dry<br>weight) | pH<br><br>(soil:H <sub>2</sub> O<br>weight<br>prop.1:2) | CEC<br>per unit<br>dry weight<br>(meq/100 g) | Metal ion<br>saturation<br>(%) | Concentration of extractable<br>cation per unit dry weight |                                                   |
|--------------------|---------------------------|----------------------------------------|---------------------------------------------------------|----------------------------------------------|--------------------------------|------------------------------------------------------------|---------------------------------------------------|
|                    |                           |                                        |                                                         |                                              |                                | Ca<br>in neutral<br>1 M NH <sub>4</sub> OAc<br>(mg/g)      | Cd<br>in 0.05 M<br>Na <sub>2</sub> EDTA<br>(ug/g) |
| 0-5                | 15.6                      | 67.3                                   | 6.8                                                     | 102                                          | 90.4                           | 16.3                                                       | 1.15                                              |
| 5-10               | 13.6                      | 57.8                                   | 6.5                                                     | 89                                           | 87.0                           | 14.3                                                       | 0.90                                              |
| 10-20              | 18.4                      | 41.2                                   | 6.1                                                     | 62                                           | 81.4                           | 9.1                                                        | 0.66                                              |
| 20-30              | 19.0                      | 38.4                                   | 6.2                                                     | 56                                           | 77.3                           | 7.8                                                        | 0.55                                              |
| 30-40              | 12.9                      | 56.0                                   | 6.3                                                     | 74                                           | 77.1                           | 10.1                                                       | 0.62                                              |
| 40-50              | 12.8                      | 65.7                                   | 6.4                                                     | 81                                           | 77.0                           | 10.7                                                       | 0.57                                              |

Tab. 1. Physical and chemical properties of the soil in August, 1973.



month and July the warmest. From the end of November to March, some of the precipitation falls as snow. A snow cover less than 20 cm deep persists for about 40-50 days (Atlas över Sverige 1953-1971:31).

During the study year, 1974, the monthly mean temperature of January to April was 1-4 °C above normal (the thirty-year mean) (Fig. 1). With the exception of the somewhat cooler July, the summer and early autumn had normal temperatures. The annual precipitation in 1974, 574 mm, and the mean precipitation of most of months was almost normal. Less rain than usual fell in March to May and in July, while the precipitation in October was more than twice the normal.

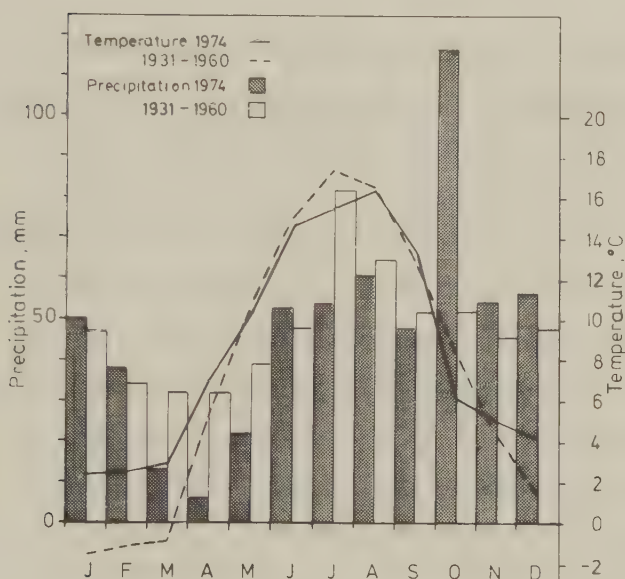


Fig. 1. Monthly mean precipitation and temperature at Kristianstad 1974 and as mean of the period 1931-1960. From SMHI (1974).

## 5 METHODS

### 5.1 Field and laboratory procedure

Ninety square plots (1 m<sup>2</sup>) were distributed regularly in a network within the study area of 25 x 40 m. The distance between adjacent plots borders was 1 m. All plots were numbered and thirty control and sixty experimental plots intended for cadmium treatment were randomized. Two concentrations of cadmium in the soil were used. The amount of cadmium added,

was calculated to give per unit dry weight of soil in the top 20 cm; 25 µg/g and 250 µg/g. There were thirty plots of each concentration. The untreated and cadmium treated plots are named control, low Cd and high Cd, respectively.

The cadmium treatments were applied in November 1973. A laboratory test showed that soil pH was unchanged by a mixture of  $\text{CdCl}_2:\text{CdAc}_2$  (1:1), so this was used for treatments. Most of the litter was temporarily removed from each plot, which was then sprinkled with 10 l of cadmium solution. Another 10 l of water were supplied after a few hours and the litter put back on the plot. The control plots were treated in the same way, but received 10 l of water in place of cadmium solution.

Samples were taken during 1974 on six occasions, chosen with regard to the development and growth of Filipendula. The first sampling occasion was 20-21 April and the final one 10-11 November. Before the first sampling occasion, five control and ten cadmium treated plots (five of each concentration) were randomly designated for each harvest. Due to a possible uneven distribution of cadmium at the edges of the plots, only the central 0.75 x 0.75 m was harvested. All plant matter was cut off at ground level and the litter collected from the same area. The few bryophytes were excluded. The below-ground plant matter was sampled in the same plots. A stainless steel cylinder with a sharp, serrated edge and with an inner diameter of 20 cm, was used. Two samples, 20 cm deep, were taken from diagonally opposite corners, 25 cm apart.

In the laboratory, the aboveground material was separated into species. Live shoots of Filipendula were counted and their length measured. They were then fractioned into stems green leaves, yellowing leaves and inflorescences of buds, flowers and seeds. The fresh litter (1974) was separated from that of the previous years.



The soil cores were sliced into sections of 0-5 cm, 5-10 cm and 10-20 cm. Using a pair of tweezers, the belowground organs of Filipendula including living and dead rhizomes, roots formed during 1974, older live roots, dead roots and roots of other species were separated from the soil. The new roots of Filipendula were white to light brown, whereas the older ones were darker brown. The distinction between new and old roots and between live and dead ones was made visually, based on colour and morphology. As the same person carried out all the work, the sorting was performed in the same way throughout. Belowground material was rinsed rapidly with deionized water. The different fractions of the living plant material and litter both above and below ground were dried at 85 °C and weighed. All results are given as dry weight.

In March 1975, an experiment with litter bags started. The litter, leaf-blades of Filipendula, was collected from a non treated area in October 1974. It was dried at room temperature, and ca. 2 g put into 10 x 10 cm terylene net bags with a mesh size of 1 mm. To get a standard moisture content, the litter bags were placed in an exsiccator for 24 h before weighing. In the field the litter was temporarily removed from the plots and the bags were placed on the soil surface. A total of 180 bags were put out: thirty each on two control and two of each concentration of cadmium treated plots. To prevent displacement by animals, the bags were covered with chicken wire. The removed litter was then put back. Five litter bags from each control and each treatment plot were collected on each sampling occasion, the first one in June 1975 and the last one in May 1977. Before drying the bags at 85°C, roots and animals, which had penetrated the meshes, were carefully removed. After some days at room temperature and in an exsiccator for 24 h, the bags were weighed.

## 5.2 Calculations and statistical treatment

The results showed considerable variation, and with so few (usually five) replicates the usual parametric statistical

tests are of doubtful validity. The non-parametric test (Wilcoxon's two sample test and Kruskal-Wallis one-way analysis of variance, Siegel, 1956) were used therefore, except where there were more than five replicates or for regression equations, estimating the rate of mortality of old roots and of litter disappearance.

The annual net primary production of aboveground organs was estimated by four different methods of calculation and that of belowground organs by another four methods. Methods C, D, G and H were applied to the Filipendula material only whereas methods E and F were suitable only at the calculations of the belowground production of the controls.

Aboveground net primary production was calculated in the following ways:

- A) as the difference between maximum and initial total biomass.
- B) as the difference between maximum and initial total biomass + current dead material at maximum biomass.
- C) according to the method of Wiegert and Evans (1964) with regard to the disappearance of litter formed during the current season.
- D) by summing the differences between maximum and initial biomass of the separate organs.

Belowground net primary production was calculated in the following ways:

- E) as the difference between maximum and initial total biomass.
- F) by summing the differences between maximum and minimum biomasses of the separate organs of Filipendula + other species.
- G) by summing seasonal increase of rhizome and new root biomass.
- H) by applying the field data of rhizome and new root biomass to regression equations, from which the calculations were made.



## 6 RESULTS

## 6.1 Above ground

6.1.1 Density and length of Filipendula shoots

In the later part of April, the hibernating shoots of Filipendula were about 10 cm tall. At maximum recorded biomass in August, when buds, flowers and seeds were all present, the control shoots had a mean length of 80 cm and 22% were fertile (Tab. 2). In the most frequent length class, 50-69 cm, only a few shoots were fertile, but the proportion increased in the longer shoot classes (Fig. 2).

| Treatment | Length (cm) | Density of shoots ( $m^{-2}$ ) | Fertile shoots (%) |
|-----------|-------------|--------------------------------|--------------------|
| Control   | 80          | 52                             | 22                 |
| Low Cd    | 68 ***      | 52                             | 22                 |
| High Cd   | 59 ***      | 30                             | 36                 |

Tab. 2. Average length, density of shoots and percentage of fertile shoots of Filipendula on 4 August, 1974. Significant difference from the control at \*\*\*  $p \leq 0.001$ .

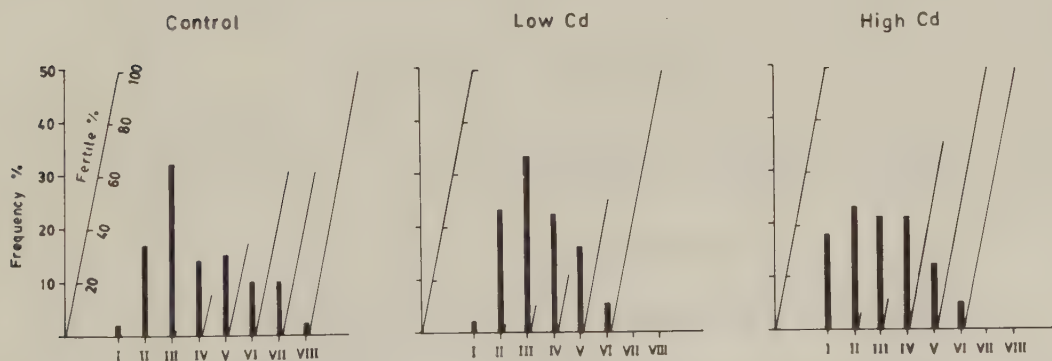


Fig. 2. The distribution in different length classes of Filipendula shoots and percentage fertile shoots in the separate classes on 4 August, 1974.

|                 |                    |
|-----------------|--------------------|
| I: 10 - 29 cm   | V: 90 - 109 cm     |
| II: 30 - 49 cm  | VI: 110 - 129 cm   |
| III: 50 - 69 cm | VII: 130 - 149 cm  |
| IV: 70 - 89 cm  | VIII: 150 - 169 cm |

Treatment with cadmium reduced the proportion of taller shoots (Fig. 2). The most frequent length class of shoots in the low Cd plots was the same as in the controls but no shoots longer than 130 cm were recorded. High Cd treatment gave a fairly even distribution of the shoots between the four lowest length classes. The low Cd treatment did not affect the average density of shoots nor the percentage of fertile shoots but the average length was 12 cm less than in the controls (Tab. 2). In the high Cd plots the average length was 21 cm less than that in control plots and the density of shoots reduced by 42%. However, the percentage share of fertile shoots increased by 39%.

The influence of cadmium was also noticeable in the field. Many leaves, especially those in the high Cd plots, had a yellow-green and curled appearance and the shoots were stunted.

#### 6.1.2 Biomass relations in the herb layer

At maximum biomass in August, Filipendula accounted for 73% of total aboveground biomass in the controls. The percentage shares of the most common other species were for Galium aparine 8%, Galeopsis tetrahit 7%, Urtica dioica 4%, Thalictrum flavum 4% and Vicia cracca 2%. However, the distribution of these species was very irregular between the plots.

The percentage shares of Filipendula in the low and high Cd plots reached 82% and 78%, respectively.

#### 6.1.3 Seasonal changes of Filipendula biomass

Filipendula starts its development of new aboveground organs in the autumn. Some growth may occur during winter and early spring. Between the two harvest occasions on 20-21 April and 9-10 June, there was rapid growth of the aboveground organs (Figs. 3 and 4). During this period, the biomass of the

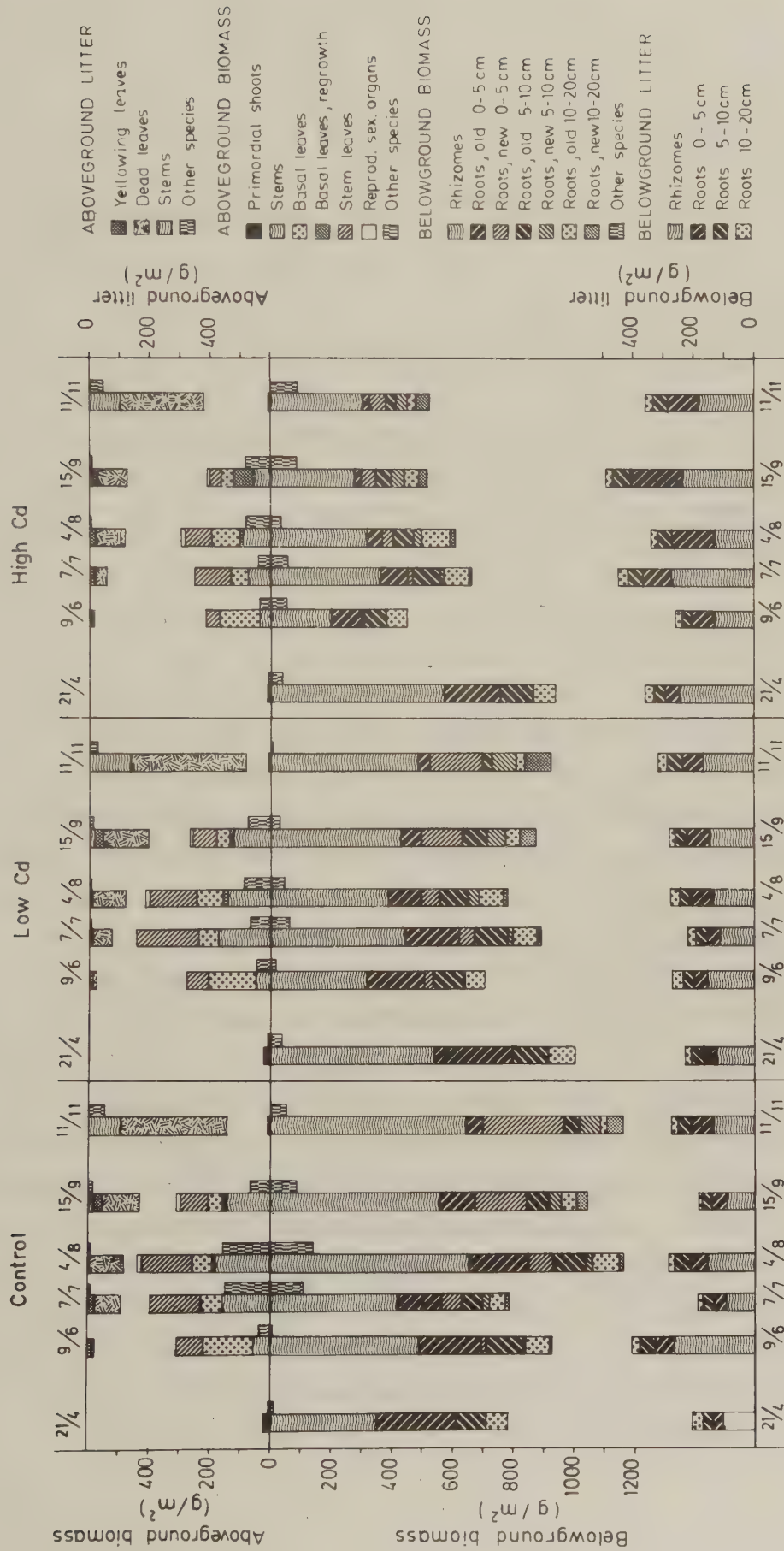


Fig. 3. Dry weights of above- and belowground organs from April to November, 1974.



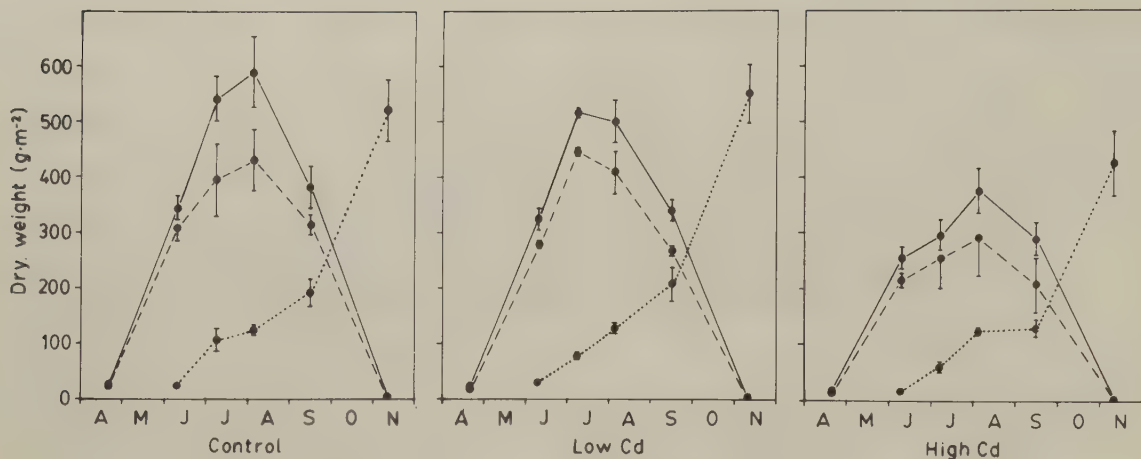


Fig. 4. Seasonal changes in aboveground biomass and litter dry weight. Vertical bars represent standard error of mean ( $n=5$ ). ●—● all species, ●—● *Filipendula*, ●---● litter.

control plots increased from  $21 \text{ g/m}^2$  to  $304 \text{ g/m}^2$ . The basal leaves, attached to the stem at the ground level, accounted for the main part of the growth (Fig. 3). At the beginning of June they made up 66% of the total biomass. This high growth rate in spring and early summer decreased somewhat in June, when stems and stem leaves accounted for the highest proportion of biomass increase. About 60% of the basal leaf biomass died during the development of the stem leaves, probably because of the increasing shade. The ratio of stem to leaf biomass remained nearly constant and there was only a slight increase in total biomass from early July to the beginning of August, at which time the biomass reached a maximum of  $430 \text{ g/m}^2$  and the plants were in flower. The flowering period of *Filipendula* was prolonged and buds, flowers and green seeds were all found in August. The sexual reproductive organs formed a very small proportion of total aboveground biomass. Although the whole inflorescence was included, the dry matter accounted for only 2%. At the harvest in the middle of September, the percentage share of almost ripe seeds averaged 4%.

After biomass maximum was reached, there was a rapid decline of green material in late summer. Loss of stem leaves, in particular, accounted for this decrease. Some development of new basal leaves had begun in July and continued through August and September. At the beginning of November only new primordial shoots of the following year could be found. The average weight of these was  $3 \text{ g/m}^2$ .

In the low Cd treated plots, the seasonal development of above-ground biomass did not differ to any degree from that of the control ones, but the biomass maximum,  $442 \text{ g/m}^2$ , occurred earlier, in July (Fig. 4). Throughout the season, the distribution of biomass of stem, leaf and sexual reproductive organs was almost the same as in the controls (Fig. 3). Only the amount of seeds in September was 58% lower than in the controls ( $0.05 \geq p > 0.01$ ).

In the high Cd plots, growth was retarded as early as June with a biomass increase from  $13 \text{ g/m}^2$  in April to only  $215 \text{ g/m}^2$  in June (Fig. 4). Maximum biomass coincided with, but reached only 67% of that of the control at the harvest in August. The development and growth of stems and stem leaves was particularly affected, with biomass reductions of 52% and 48%, respectively. In contrast the basal leaf biomass accounted for a greater percentage of total aboveground biomass and the regrowth of new basal leaves was more vigorous in the high Cd plots than in the controls. In the middle of September, the recorded amount of new basal leaves reached  $66 \text{ g/m}^2$  in the high Cd plots, making up 45% of total leaf biomass. This was significantly greater ( $0.01 \geq p > 0.001$ ) than in the controls with  $11 \text{ g/m}^2$  (7%). In August, the high Cd plots showed much the same biomass of buds, flowers and seeds as the controls but the further development of the seeds was seriously disturbed and the average weight in September was less than 18% of that of the controls ( $0.05 \geq p > 0.01$ ).

#### 6.1.4 Seasonal changes of other species biomass

Maximum biomass of other species in both the control and Cd treated plots occurred at the beginning of August (Fig. 3). From almost the same recorded biomass in April and June, the growth in the Cd treatments was much smaller during the summer. At maximum there was no great difference between the biomass amounts in the low and high Cd plots but both were about 45% lower than the control. The results were very variable however, and not statistically significant different.

#### 6.1.5 Net primary production

Annual net primary production, including all species and calculated as the difference between maximum and initial biomass values (Method A) was  $562 \text{ g/m}^2$  in the control plots (Tab. 3). The other estimate of production, including newly formed litter (Method B) gave  $684 \text{ g/m}^2$ . By using the recorded disappearance rate from the litter bags experiment (regression coefficient March-November, Tab. 5), account could also be taken of the disappearance of litter between harvests (Method C). As these values were applicable to the litter of

|          | <u>Control</u> |       | <u>Low Cd</u> |       | <u>High Cd</u> |       |
|----------|----------------|-------|---------------|-------|----------------|-------|
| Method A | 562            | (409) | 489           | (422) | 359            | (278) |
| Method B | 684            | (527) | 564           | (496) | 480            | (396) |
| Method C |                | (544) |               | (528) |                | (409) |
| Method D |                | (540) |               | (558) |                | (416) |

Tab. 3. Estimations of annual aboveground net primary production using four calculation methods (all values in  $\text{g/m}^2$ ). Figures in parentheses are the contribution of Filipendula. In methods C and D, the calculations were based on Filipendula alone.



Filipendula only, no estimation of the production of other species was possible. According to method C, the annual growth of Filipendula ( $544 \text{ g/m}^2$ ) was somewhat higher than that obtained with method B. In method D, the biomass increase of the hibernating shoots during the cooler season (calculated as the difference between the weight in April and November) was included in the estimation of annual net primary production. Almost the same value ( $540 \text{ g/m}^2$ ) was recorded as with method C.

The different calculation methods show that the low Cd treatment decreased the total production of all species by 13-18% (Tab. 3). The high Cd treatment gave a corresponding decrease of 30-36%. When Filipendula is considered alone, the low Cd treatment had no consistent effect on growth: method A and D show a small increase, method B and C a small decrease compared with the control. With the high Cd treatment, net primary production was reduced by 23-25%.

#### 6.1.6 Accumulation of litter formed during 1974

The aboveground litter weights are given in Figs. 3 and 4. Litter fall was most rapid during early summer, when most of the basal leaves of Filipendula died, and during the late autumn. At the harvest in November, the average weight of accumulated current litter of all species, was  $514 \text{ g/m}^2$  in the controls, making up 75% of net primary production according to method B (Tab. 3). The contribution of Filipendula litter was  $459 \text{ g/m}^2$ .

The corresponding remaining amount of litter of Filipendula in the low and high Cd plots was  $518 \text{ g/m}^2$  and  $378 \text{ g/m}^2$ , respectively.

#### 6.1.7 Disappearance of litter

At the end of the growing season in November, the total accumulated amount of aboveground litter in the controls was 853

$\text{g/m}^2$ . Assuming a steady state, that is that the annual increment of litter equals the loss, 60% of aboveground litter would disappear within one year, giving a turnover time of ca. 1.7 years.

Old litter, mostly formed during the previous year (1973), was separated from the current year's litter. In the middle of April, the recorded quantities of old litter averaged  $720 \text{ g/m}^2$ ,  $852 \text{ g/m}^2$  and  $969 \text{ g/m}^2$  in the controls and the low and high Cd treatments, respectively (Fig. 5).

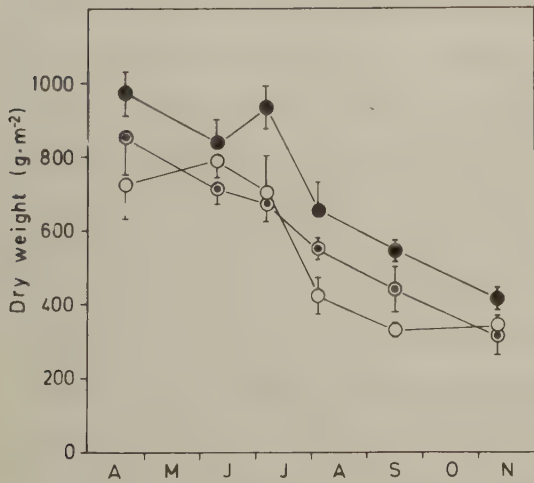


Fig. 5. Changes in dry weight of old litter during the growing season 1974.  
 ○ Control, ◐ Low Cd, ● High Cd.  
 Vertical bars represent standard error of mean (n=5).

Assuming that the rate of litter loss is a constant proportion of what is left, then the weight decrease of litter may be described by a negative exponential equation (Jenny et al. 1949, Olson 1963).  $W_t = W_0 e^{-kt}$ , where  $W_t$  is the weight at time  $t$ ,  $W_0$  is the initial weight,  $e$  is the base of natural logarithm and  $k$  is the disappearance rate coefficient. The regression,  $\ln$  dry weight of litter ( $\text{g/m}^2$ ) on time (days) was calculated for both the controls and the Cd treatments at two time periods. Although hypothetical (not considering influence of season and of factors controlling litter disappearance), the disappearance rate coefficients and time parameters, "half time" and "95% time", the time required for the disappearance of 50% and 95% of the initial weight of litter are shown in Tab. 4.

| Treatment | 21 April - 11 November |                     |                           |                          | 9 June-11 November |                     |
|-----------|------------------------|---------------------|---------------------------|--------------------------|--------------------|---------------------|
|           | k                      | r                   | "half<br>time"<br>(years) | "95%<br>time"<br>(years) | k                  | r                   |
|           |                        |                     | 0.693                     | 2.996                    |                    |                     |
|           |                        |                     | k                         | k                        |                    |                     |
| Control   | 0.0048                 | 0.75 <sup>***</sup> | 0.40                      | 1.74                     | 0.0059             | 0.76 <sup>***</sup> |
| Low Cd    | 0.0051                 | 0.83 <sup>***</sup> | 0.38                      | 1.63                     | 0.0058             | 0.83 <sup>***</sup> |
| High Cd   | 0.0044                 | 0.84 <sup>***</sup> | 0.44                      | 1.89                     | 0.0052             | 0.82 <sup>***</sup> |

Tab. 4. Regression parameters for the disappearance of old litter, calculated for two time periods, 1974. Significance level <sup>\*\*\*</sup>  $p \leq 0.001$ .

Compared to the controls, the disappearance rate was highest in the low Cd plots and lowest in the high Cd ones. However, the difference between the coefficients was not statistically significant ( $p > 0.05$ ).

To get more directly, comparable information about litter losses in controls and Cd treatments, a litter bag experiment was started in 1975. The losses were most rapid during the warmest months, July and August (Fig. 6). At the beginning of November almost 50% of the initial weight of litter had disappeared in the controls. In comparison to the disappearance rate of old litter during the time period, June to

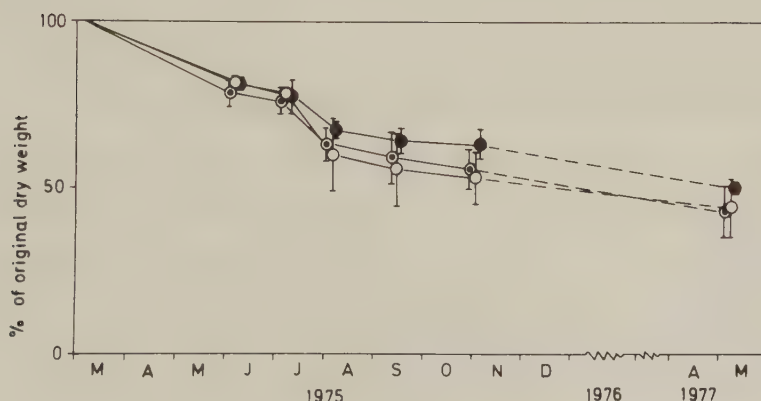


Fig. 6. Percentage changes in dry weight of *Filipendula* leaf-blade litter in litter bags from March, 1975 to May, 1977. —○— Control, —●— Low Cd, —●— High Cd. Vertical bars represent 95% confidence limit of mean ( $n=10$ ).



| Treatment | 6 March - 2 November |         |                        | 6 June - 2 November |         |
|-----------|----------------------|---------|------------------------|---------------------|---------|
|           | k                    | r       | "half time"<br>(years) | k                   | r       |
|           |                      |         | $\frac{0.693}{k}$      |                     |         |
| Control   | 0.0028               | 0.78*** | 0.69                   | 0.0038              | 0.65*** |
| Low Cd    | 0.0027               | 0.84*** | 0.71                   | 0.0036              | 0.70*** |
| High Cd   | 0.0021               | 0.91*** | 0.92                   | 0.0026              | 0.70*** |

Tab. 5. Regression parameters for the disappearance of Filipendula leaf-blade litter in litter bags, calculated for two time periods, 1975. Significance level \*\*\*  $p \leq 0.001$ .

November, 1974, the weight losses in the litter bags during the corresponding period in 1975, were considerably lower (Tabs. 4 and 5). At the end of the experiment in May 1977, more than 40% of the initial weight of litter remained.

In both the Cd treatments, the disappearance rate of litter in the litter bags was lower than in the controls. However, only between the regression coefficients of the control and the high Cd (March-November) was the difference significant at the 5% level.

## 6.2 Belowground to aboveground biomass ratios

Throughout the year, the main part of the biomass was below ground (Fig. 7). The ratio of belowground biomass of Filipendula (rhizomes and roots) to that above ground varied in the controls, from June to September, between 2.0 to 3.3. In the low and high Cd treatments the variation during the same period was 1.9 to 3.3 and 2.1 to 2.6, respectively. The contribution of other species decreased all the ratios somewhat.

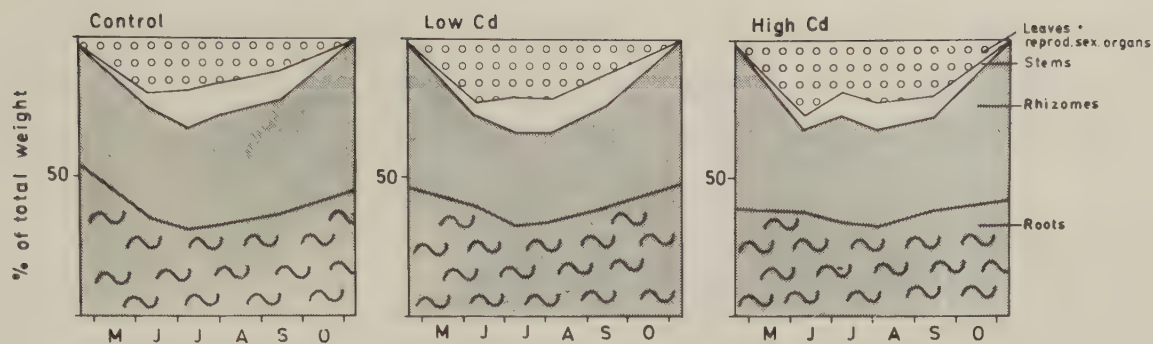


Fig. 7. Distribution of aboveground and belowground biomass of Filipendula from April to November, 1974.

### 6.3 Below ground

#### 6.3.1 Biomass of Filipendula

##### 6.3.1.1 Vertical distribution in the soil

From the intertwined rhizomes, adventitious roots spread both horizontally, almost at the soil surface, and vertically down into the soil. Most of the vertically growing roots were found in the upper 20 cm of the soil and the length of the horizontal ones seemed to be less than half a meter.

The main part of the belowground biomass of Filipendula (77-83% of that measured) was concentrated in the top 5 cm of the soil in the controls (Fig. 3). Rhizomes were found only in this section and accounted during the investigated period for about half of total belowground biomass weight. The percentage distribution of roots in the three soil sections 0-5 cm, 5-10 cm and 10-20 cm, was fairly constant for most of the growing season (Fig. 8). On average, approximately half of the old root biomass was found in the top 5 cm of the soil, while the percentage share of new roots in this section was higher, ca.70%.

The Cd treatments did not change the relations between the rhizome and root biomass weights. However, during the summer

and onwards, the percentage share of roots in the top of the soil decreased markedly in Cd treated plots, giving proportional increases in the two lower sections (Fig. 8).

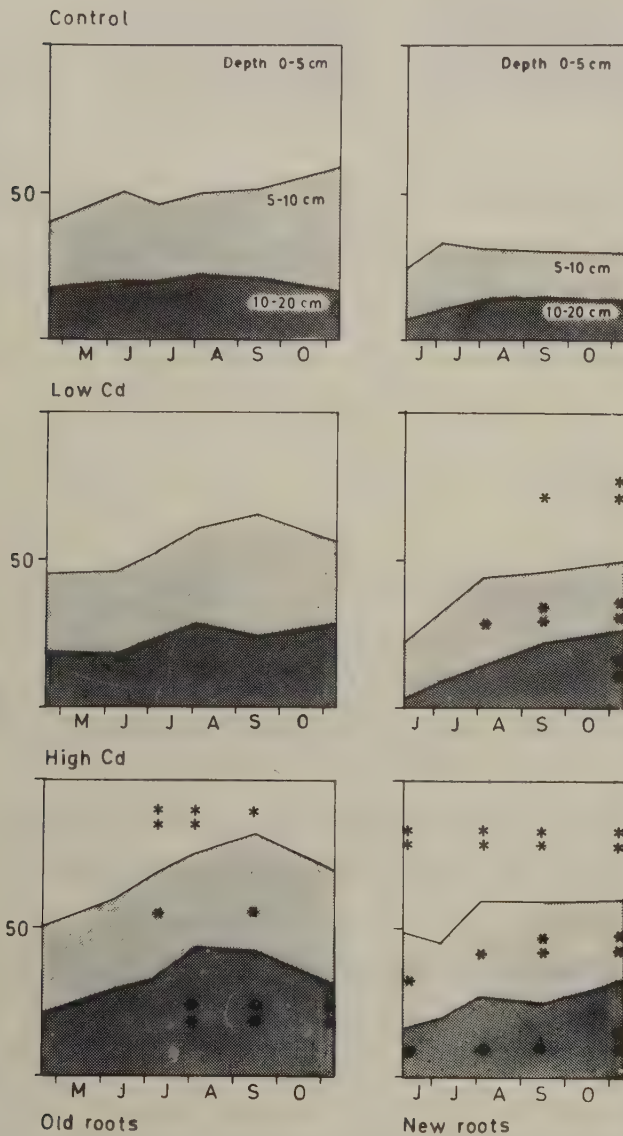


Fig. 8. Percentage distribution of *Filipendula* roots in the soil profile. Responses to cadmium supply significantly different from controls at \* 0.05  $\geq p > 0.01$  and \*\* 0.01  $\geq p > 0.001$ .

#### 6.3.1.2 Seasonal changes

In the controls, the total belowground biomass, including both rhizomes and roots, averaged  $783 \text{ g/m}^2$  in April and July and  $919 \text{ g/m}^2$  in June (Fig. 9). The following year, 1975, on 18 April, a resampling of the controls gave  $990 \text{ g/m}^2$ . Maximum biomass, ca  $1170 \text{ g/m}^2$ , coincided with that of the aboveground parts.



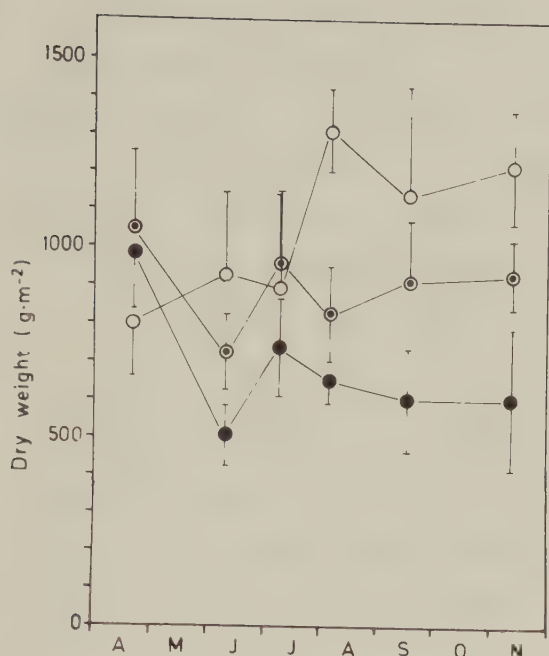


Fig. 9. Seasonal change of total belowground biomass of Filipendula. Vertical bars represent standard error of mean (n=5).

—○— Control, —○●— Low Cd,  
—●— High Cd.

In the Cd treatments, maximum biomass was reached in April, followed by a dip in June and a slight increase during the second part of the growing season. Analysis of variance indicated, that the effect of cadmium was statistically significant only in August ( $p \leq 0.01$ ).

#### 6.3.1.3 Rhizomes

Over the measurement period, the rhizome biomass tended to increase in the controls (Fig. 10). The regression coefficient for the relationship of weight on time, was different

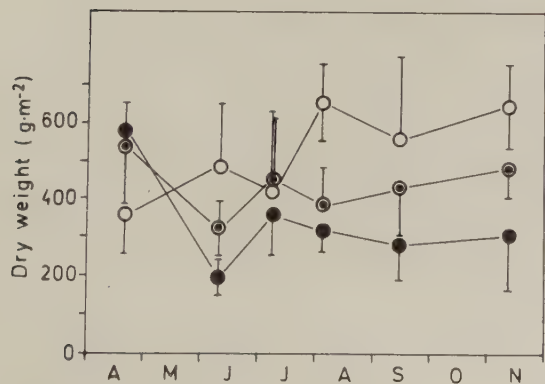


Fig. 10. Seasonal change of Filipendula rhizome biomass. Vertical bars represent standard error of mean (n=5). —○— Control,  
—○●— Low Ca —●— High Cd.

from zero at  $0.20 > p > 0.10$ . Maximum biomass,  $653 \text{ g/m}^2$ , was recorded in August, which was an increase of  $298 \text{ g/m}^2$  from minimum in April. Calculation from the linear regression over the whole growing season gave an increase of  $277 \text{ g/m}^2$ . From July to November new white rhizomes, shooting from the old ones, were noticed in some control samples. Later in the season, new rhizomes were also found in samples from the Cd treatments. The variation between samples in the amount of new rhizomes was great, so no reliable estimation of annual increment of these was possible. There seems to have been a fall of rhizome biomass in the Cd treated plots during early summer, perhaps connected with the growth of aboveground parts, but the decrease was not statistically significant at  $p \leq 0.05$ .

#### 6.3.1.4 Old roots

Maximum total biomass of old roots, mainly those formed in the previous year (1973), was recorded at the harvest in April, followed by a rapid decline during the growing season (Fig. 11). The decrease was most rapid in the top layer of the soil. The seasonal decrease of root biomass, calculated as the difference between the weight in April and November, gave an average mortality of  $0.98 \text{ g/m}^2/\text{day}$ . In the two lower sections, 5-10 cm and 10-20 cm, the corresponding rate was  $0.22 \text{ g/m}^2/\text{day}$  and  $0.24 \text{ g/m}^2/\text{day}$ , respectively. In order to facilitate comparisons within and between the control and the Cd treatments, linear regression equations were calculated between  $\ln$  dry weight ( $\text{g/m}^2$ ) and time (days). On the assumption that the rate of loss was proportional to the amount of roots remaining,  $W_t = W_0 e^{-kt}$  (cf. p 16). The regressions were calculated for each soil section, separately. In Tab. 6 are given the regression parameters and the predicted values of the quantities of old roots remaining after one year and the time when 5% of the initial quantities would remain.

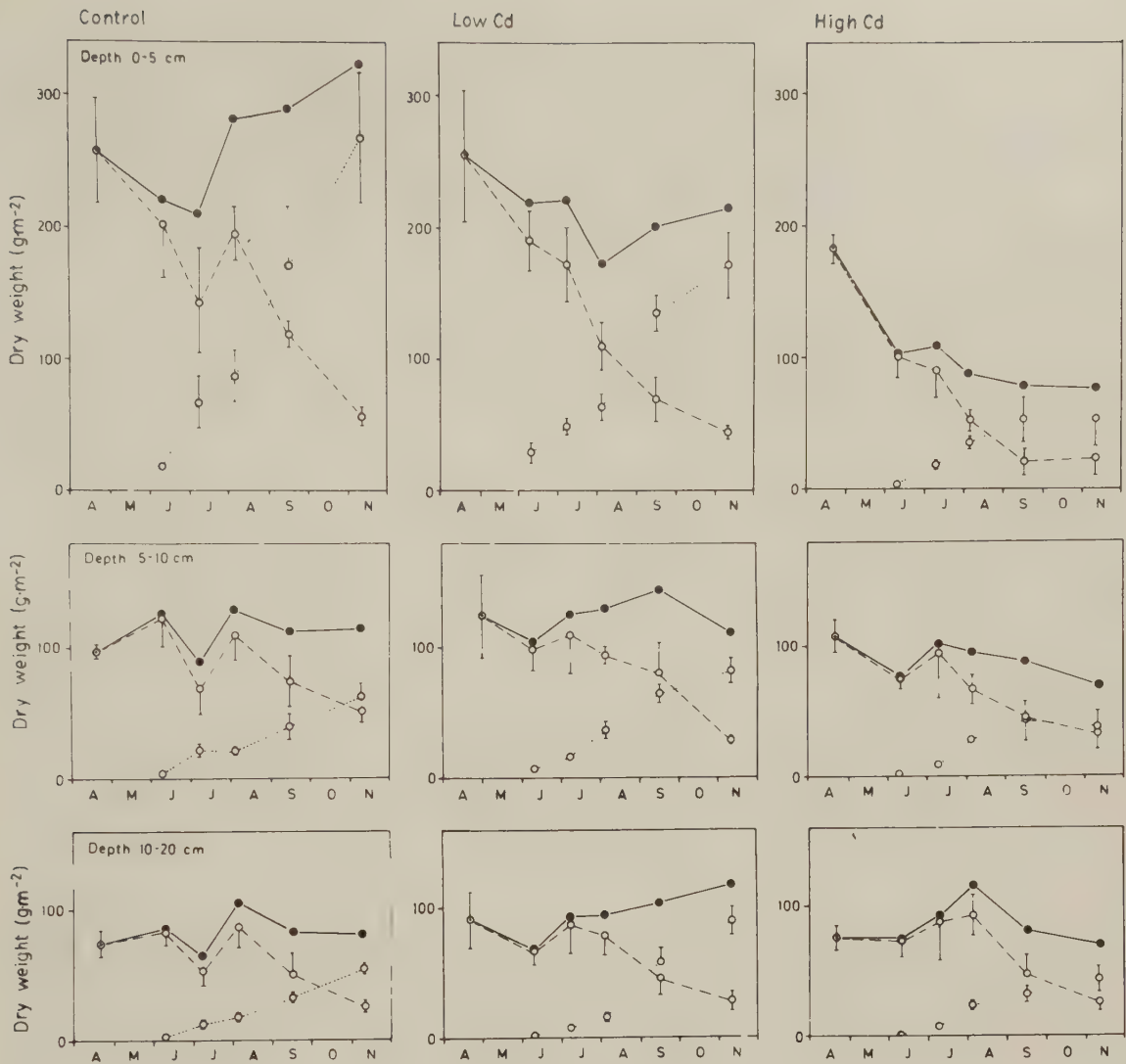


Fig. 11. Seasonal change of *Filipendula* root biomass at different soil depths. Vertical bars, representing standard error of mean ( $n=5$ ), are drawn in old and new root figures, only. ●—● old + new roots, ●—● old roots, ●.....● new roots.

The slope of the regression line, a measure of the mortality was higher in the top and the lowest soil section than in the middle section of the controls, a fact also noticed in the low Cd treatments. The effect of cadmium on root mortality was very obvious in both the Cd treatments. The slope of the regression line, computed from the 0-5 cm soil section of the high Cd treatments was 2.4 times that in the control. ( $0.01 \geq p > 0.001$ ). In the middle section (5-10 cm) the influence of cadmium was still marked, especially in the high Cd treatments, while the lowest section (10-20 cm) was only slightly affected.



|                |         | $W_{O_2}$<br>(g/m <sup>2</sup> ) | k      | r                   | Alive<br>after<br>one year<br>(g/m <sup>2</sup> ) | 5% alive<br>after<br>(years) |
|----------------|---------|----------------------------------|--------|---------------------|---------------------------------------------------|------------------------------|
| <u>Control</u> |         |                                  |        |                     |                                                   |                              |
| section        | 0-5 cm  | 258.4                            | 0.0065 | 0.67 <sup>***</sup> | 25.0                                              | 1.3                          |
|                | 5-10 "  | 103.1                            | 0.0033 | 0.37 <sup>*</sup>   | 31.4                                              | 2.5                          |
|                | 10-20 " | 89.0                             | 0.0055 | 0.59 <sup>***</sup> | 12.3                                              | 1.5                          |
| <u>Low Cd</u>  |         |                                  |        |                     |                                                   |                              |
| section        | 0-5 cm  | 273.4                            | 0.0093 | 0.82 <sup>***</sup> | 9.6                                               | 0.9                          |
|                | 5-10 "  | 104.1                            | 0.0043 | 0.44 <sup>*</sup>   | 22.1                                              | 1.9                          |
|                | 10-20 " | 97.0                             | 0.0062 | 0.56 <sup>**</sup>  | 10.4                                              | 1.3                          |
| <u>High Cd</u> |         |                                  |        |                     |                                                   |                              |
| section        | 0-5 cm  | 210.0                            | 0.0158 | 0.74 <sup>***</sup> | 0.7                                               | 0.5                          |
|                | 5-10 "  | 127.0                            | 0.0090 | 0.60 <sup>***</sup> | 5.0                                               | 0.9                          |
|                | 10-20 " | 101.8                            | 0.0065 | 0.54 <sup>**</sup>  | 9.8                                               | 1.3                          |

Tab. 6. Regression parameters for the seasonal decrease of Filipendula old root biomass at different depths in untreated and cadmium treated soil. Levels of significance, \*  $0.05 \geq p > 0.01$ , \*\*  $0.01 \geq p > 0.001$ , \*\*\*  $p \leq 0.001$ .

#### 6.3.1.5 New roots

The formation of new roots started some time between the harvests in April and June. In the control plots, the increment was approximately linear with time throughout the measurement period (Fig. 11). Fitted linear regressions are shown in Tab. 7. The formation of new roots was considerably greater in the 0-5 cm section than deeper in the soil. In November, the biomass attained a maximum of 268 g/m<sup>2</sup>, equal to the net increment over the season and 70% of total new root formation of the soil profile.

Harvesting was finished in November when all the aboveground parts, except for primordial shoots, were frozen and dead.

There was a greater biomass of new roots at this last harvest than in the penultimate one, so the time of the maximum is not known. The biomass at the last harvest has been assumed to be the maximum in all calculations.

|                 | Regression equation | r       |
|-----------------|---------------------|---------|
| <u>Control</u>  |                     |         |
| Section 0- 5 cm | $y = 1.61x - 67.9$  | 0.79*** |
| 5-10 "          | $y = 0.37x - 13.0$  | 0.78*** |
| 10-20 "         | $y = 0.33x - 15.6$  | 0.92*** |
| <u>Low Cd</u>   |                     |         |
| Section 0- 5 cm | $y = 0.98x - 25.6$  | 0.86*** |
| 5-10 "          | $y = 0.51x - 19.6$  | 0.90*** |
| 10-20 "         | $y = 0.61x - 37.5$  | 0.89*** |
| <u>High Cd</u>  |                     |         |
| Section 0- 5 cm | $y = 0.33x - 6.5$   | 0.56**  |
| 5-10 "          | $y = 0.25x - 6.2$   | 0.56**  |
| 10-20 "         | $y = 0.28x - 11.8$  | 0.78*** |

Tab. 7. Linear regressions for Filipendula new root biomass ( $y$ ,  $\text{g/m}^2$ ) during the growing season ( $x$ , days) at different depths in untreated and Cd treated soil. Levels of significance, \*\*  $0.01 \geq p > 0.001$ , \*\*\*  $p \leq 0.001$ .

With the assumptions of no growth or death of new roots during the winter, the turnover or annual increment of new roots to total root biomass can be calculated. On average 75% of the total root biomass of the soil profile would be replaced within one year. The highest turnover occurred in the top section (82%) and the lowest in the middle one (55%).

The cadmium treatment caused demonstrable disturbance of the formation of new roots. The horizontal growth was obviously retarded especially during the second part of the season

and vertical growth became more pronounced. In the most affected soil section, 0-5 cm, the net seasonal increment reached maximum in November,  $172 \text{ g/m}^2$  in the low Cd treatments (64% of the control) and only  $53 \text{ g/m}^2$  in the high Cd treatments (20%) (Fig. 11). Analysis of variance indicated a significant effect of cadmium ( $p \leq 0.01$ ). This inhibition of root formation was partly compensated by proportionately greater growth in the two lower sections.

### 6.3.2 Net primary production

According to method E (cf. p. 8), the total annual net primary production of belowground organs was  $511 \text{ g/m}^2$  in the controls (Tab. 8). An estimation by method F gave  $609 \text{ g/m}^2$ , of which the belowground organs of species other than Filipendula made up 22%. The estimated production of Filipendula alone, using method G, was  $684 \text{ g/m}^2$ , which is 30% greater than the estimation by method F. The results calculated from the regression equations (method H) were in good agreement with those of method G.

Methods E and F could not be applied to the Cd treated plots, because the maximum biomass coincided with the initial biomass in April. Although, there was no seasonal increase of the total root biomass, new roots did form. According to method G, the annual increment of these was  $343 \text{ g/m}^2$  in the low Cd treated soil and  $133 \text{ g/m}^2$  in the high Cd treated one. In comparison with the controls, the low and high Cd treatments reduced the estimated annual production of roots by 11% and 66%, respectively.



| Treatment                                     | Method     |            |            |            |
|-----------------------------------------------|------------|------------|------------|------------|
|                                               | E          | F          | G          | H          |
| <u>Control</u>                                |            |            |            |            |
| Rhizomes                                      |            | 298        | 298        | 277        |
| Roots, 0-5 cm                                 |            | 115        | 268        | 262        |
| Roots, 5-10 cm                                |            | 39         | 65         | 63         |
| Roots, 10-20 cm                               |            | 24         | 53         | 52         |
| <u>Total, Fil. ulm.</u>                       | <u>386</u> | <u>476</u> | <u>684</u> | <u>654</u> |
| Other species                                 |            | 133        |            |            |
| <u>Total, including</u><br><u>all species</u> | <u>511</u> | <u>609</u> |            |            |
| <u>Low Cd</u>                                 |            |            |            |            |
| Rhizomes                                      |            |            | -          | -          |
| Roots, 0-5 cm                                 |            |            | 172        | 175        |
| Roots, 5-10 cm                                |            |            | 82         | 85         |
| Roots, 10-20 cm                               |            |            | 89         | 88         |
| <u>Total, Fil. ulm.</u>                       |            |            | <u>343</u> | <u>348</u> |
| <u>High Cd</u>                                |            |            |            |            |
| Rhizomes                                      |            |            | -          | -          |
| Roots, 0-5 cm                                 |            |            | 53         | 61         |
| Roots, 5-10 cm                                |            |            | 37         | 45         |
| Roots, 10-20 cm                               |            |            | 43         | 44         |
| <u>Total, Fil. ulm.</u>                       |            |            | <u>133</u> | <u>150</u> |

Tab. 8. Estimations of annual belowground net primary production, calculated by four methods. All values are given in  $\text{g/m}^2$ .

### 6.3.3 Accumulation and disappearance of root litter

Although old roots were dying throughout the growing season, there was no statistically significant change in the amount of root litter in any soil section of the control plots (Fig. 11). During the greater part of the season, the percentage

share of root litter weight to the total weight of root biomass + root litter was fairly constant in the uppermost 10 cm of the soil profile (Fig. 12). Only in the 10-20 cm section was there a decreasing proportion of root litter during the summer months.

In the Cd treated plots, the amount of root litter increased, especially in the upper 5 cm of the soil profile. During the second half of the growing season, the percentage share of root litter in this section was 3.0-4.6 times higher in the high Cd plots than in the control plots (Fig. 12). In the low Cd plots, the corresponding percentage shares ranged from 1.5-1.8 times.

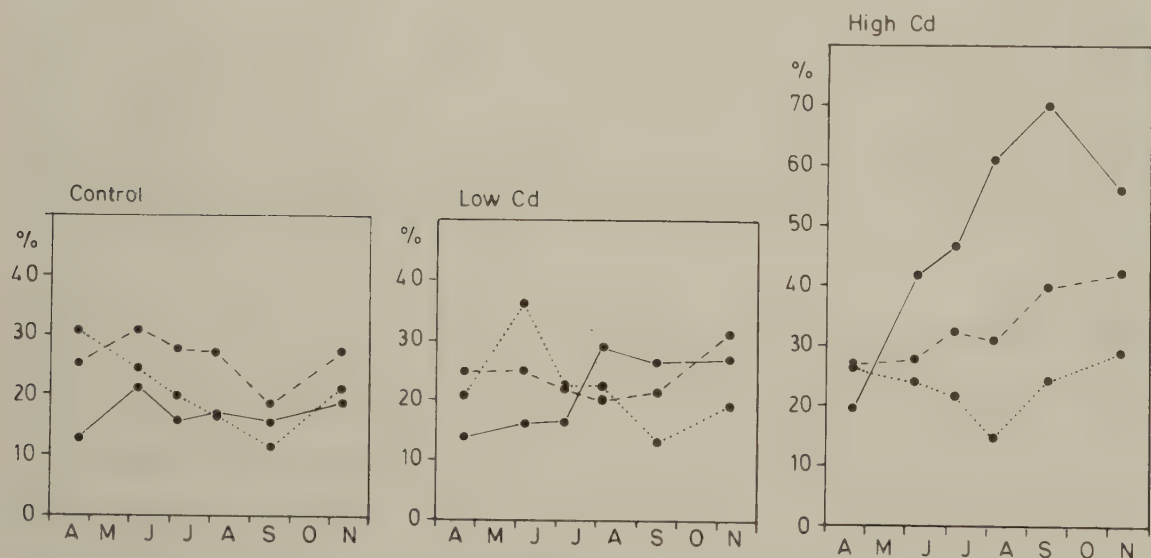


Fig. 12. Percentage share of root litter dry weight to total weight of root biomass + root litter at different soil depths.

●—● 0-5 cm, ●—● 5-10 cm, ●.....● 10-20 cm.

## 7 DISCUSSION

### 7.1 Aboveground biomass and net primary production of the controls

Throughout the growing season, Filipendula accounted for the main part of the biomass. The dense root layer and leaf canopy could outcompete most other species. Small 'depressions' between the 'tussocks' of Filipendula, may give other species a few opportunities to germinate, but the rapid development of the hibernating shoots of Filipendula from April onwards rapidly limits the light supply for growing seedlings. The rather thick layer of litter may also prevent seed germination although the seedlings of e.g. Galium aparine have extended hypocotyls facilitating the penetration of the litter (Al-Mufti et al. 1977).

The maximum recorded aboveground biomass of both Filipendula alone ( $430 \text{ g/m}^2$ ) and of all species ( $586 \text{ g/m}^2$ ) was higher than has been reported from other communities with dominant Filipendula. In a tall herb meadow in Linnebjerg, SW Sweden, the biomass of Filipendula reached a maximum of  $324 \text{ g/m}^2$  in July and for all species the biomass reached  $470 \text{ g/m}^2$  (Andersson 1970). Values ca. 15% lower were recorded in south Yorkshire, England, but the summer during which the studies were made, was unusually hot and dry and wilting Filipendula shoots were observed as early as July (Al-Mufti et al. 1977).

In the work reported here, the annual net primary production was estimated in four ways, of which method A is the one generally used in other studies. By comparison with methods which account for turnover of organic material between the measurements, method A has often proved to give a marked underestimation of production (Wiegert and Evans 1964, Wallentinus 1973, Korobeinikova 1975, Kirby and Gosselink 1976, Williamson 1976). Method B also underestimates production, especially in plant communities with a high rate of litter disappearance. Considering the estimated production values of



Filipendula alone, the difference between methods B and C was 3%, suggesting only a low disappearance rate. The disappearance rate of litter used in method C was that obtained from the litter bag experiment. Although this rate was lower than that obtained for unconfined old litter, the rate may be comparable to the disappearance rate of current litter, as the greatest weight losses would be due to leaching during the first weeks after leaf fall (Bocock et al. 1960). In method D, calculations were made from the seasonal biomass increments of the separate organs of Filipendula. Although some death of organs during development may have been disregarded the underestimation due to this would probably be small.

Inaccuracy, resulting from underestimation is to some extent balanced by overestimation, the extent of each depending on the method used. Besides biomass increase, resulting from photosynthetic activity, there is also an increase due to translocation of nutrient elements and organic matter from senescent organs into living ones (Oland 1963). In Solidago altissima, Iwaki et al. (1969) assumed this translocation to correspond to 10% of the dry matter content in mature leaves. During early summer especially, when many of the basal leaves died, such a translocation cannot be ignored.

At the beginning of the growing season, there may be a similar transport of nutrient reserves from rhizomes to developing aboveground organs (Mooney and Billings 1960, Fonda and Bliss 1966, Otzen and Koridon 1970). There seemed to be some growth of the hibernating shoots of Filipendula even during the winter and early spring, although no measurements were made during this time. Fonda and Bliss (1966) supposed such early growth in alpine species to be largely a translocation of nutrient reserves from the rhizomes. A biomass increase above ground during the winter may be due to such translocation, but photosynthesis during warm spring days cannot be ruled out. As the first harvest in this study did not take place

until 20 April, photosynthesis probably contributed more to the recorded biomass increase than translocation. In all cases, biomass increment due to translocation can hardly be ignored though difficult to estimate with current methods.

Another source of error in estimating net primary production was weight losses due to fungal attack (mildew) on leaves and grazing by animals, especially insects. Probably negligible, these weight losses were ignored. Corrections were only made for some Filipendula shoots, which were grazed by an elk in early summer.

The estimated annual aboveground net primary production by all species was ca.  $700 \text{ g/m}^2$  and was in the same range as that recorded in similar meadows with Filipendula (Andersson 1970, Korobeinikova 1975).

## 7.2 Belowground biomass and net primary production of the controls

The largest proportion of the total biomass was below ground. Like many other perennial plant species with extensive rhizome and root systems, the belowground to aboveground biomass ratio of Filipendula attained high values.

Over the main part of the growing season, more than half of the belowground biomass was in rhizomes, but Filipendula grows in clumps and the distribution of the rhizomes was irregular. In consequence, the variation of the rhizome replicates was relatively large, and this is reflected in the variation of the total belowground biomass. With hindsight it is apparent that too few replicates were measured, so there are few statistically significant differences in seasonal growth or in the effects of cadmium.

There are several reports of a decrease in rhizome biomass at the beginning of the growing season, possibly a result of transport of nutrients upwards to developing aboveground

organs (Fonda and Bliss 1960, Mooney and Billings 1960, Iwaki et al. 1969, Otzen and Koridon 1970). In Miscanthus sacchariflorus (Mutoh et al. 1968) and in Tussilago farfara (Ogden 1974) there was a decrease in rhizome weight during winter and early spring. Up to 50% of the reserve substances in the rhizomes of Polygonum bistortoides was used within one week in early spring (Mooney and Billings 1960) and Bernard (1974) calculated that perhaps 30% of the aboveground growth was maintained from belowground organs. For Filipendula in the present study any such decrease was not obtained but a small decrease cannot be ruled out, as such a change would be masked in the variation between the samples.

An estimation of annual net primary production of rhizomes, based upon the seasonal biomass change, proved to be difficult due to the sample variation. The biomass increase over the measurement period was statistically only weakly ascertained. Part of the biomass increment consisted of newly formed rhizomes but part may have been a result of translocation of nutrients into old rhizomes from the aboveground organs (Fonda and Bliss 1966, Mutoh et al. 1968, Iwaki et al. 1969, Otzen and Koridon 1970, Fiala 1973). This export of nutrients from rhizome to aboveground parts early in the season probably causes the minimum in rhizome weight, but may be looked on as a loan, which is soon repaid. (Fonda and Bliss 1966, Mutoh et al. 1968). Not until this loan is repaid, would there be a real net increase of reserve substances. Therefore, estimations of net primary production, based upon minimum (due to translocation) and maximum biomass values are probably overestimations which to varying extent may be counterbalanced by losses due to death of rhizomes and rhizome tissues.

The growth rhythms and biomass increments of roots vary both with age and depth in the soil (Dahlman 1968, Ignatenko et al. 1968, Nilsson 1970). Several techniques, intended to determine the vitality of roots have been reported, but they may be of no practical use in larger root samples.



For Filipendula, fractioning of roots for age and vitality by colour and morphology seemed to be satisfactory, though it would not necessarily be so for plants with finer and more complex root systems.

A mainly horizontal spread of the root system, typical of several perennial plant species (Plasilova 1970) exceeded the vertical one, which gave a relatively high concentration of roots in the uppermost 5 cm of the soil profile. The percentage of roots in this section averaged 57% and was fairly constant for most of the growing season and higher for the new roots than for the older ones. In many other plant communities, similar values, ranging from 51-75% have been reported (Speidel and Weiss 1971, Tyler 1971, Plewczynska-Kuras 1976).

The formation of new roots, initiated some time in the period April to June, was greatest in the top section, with some time delay in the lower sections. Nilsson (1970) ascribed this delay to lower temperature, but in the present study, the delay was more probably due to the growth dynamics of the roots, which were arising from the rhizomes and like a wave moving downwards. Not until November did the measured biomass of new roots reach maximum. In the top section this maximum was slightly higher than the initial weight of roots in April.

While new roots formed, old ones died. The highest rate was in the upper part of the soil. The death rate of roots was high in the lowest section too, probably strongly affected by the high ground water level, poor aeration and formation of hydrogen sulfide.

Belowground production in most ecosystem is particularly difficult to estimate. In most published works, an estimation of belowground production has been made from the difference between maximum and minimum biomass (among others Wiegert

and Evans 1964, Dahlman and Kucera 1965, Ignatenko et al. 1968, Bernard and McDonald 1974, Tumidajowicz 1976). This calculation greatly underestimates primary production however, especially in plant communities with a high rate of root turnover.

In this study, using this difference method for total root biomass, an annual production of  $155 \text{ g/m}^2$  was obtained, giving an annual turnover of ca. 30%. This value is in good agreement with earlier works, with turnover times ranging from 2 to 4 years (Ignatenko et al. 1968, Dahlman and Kucera 1965, Bartos and Jameson 1974, Tumidajowicz 1976), but is nevertheless probably an underestimation. During the growth period, the total biomass of roots increased by 30%, even though an average of 70% of the initial amounts of roots in April died. The calculated high annual turnover values (on average 75%) indicated a much greater annual regeneration of the root system than has been reported in most other earlier studies, though it was proposed from a hypothetical model by Bartos and Jameson (1974). In some perennial grass species Stuckey (1941) found a still higher turnover rate of roots with total replacement every year.

Depending on the method used, the total belowground production of Filipendula ranged from  $386 \text{ g/m}^2$  to  $684 \text{ g/m}^2$ . If all species are included, the production reached more than  $800 \text{ g/m}^2$ .

### 7.3 Above- and belowground litter of the controls

The amount of current year's aboveground litter, accumulated by November, was greater than expected. From total aboveground net primary production of all species (according to method B) about 25% had disappeared at the beginning of November. Weight losses due to translocation and physical leaching might already be important by the time of senescence, however. Three herbaceous species in a deciduous woodland showed

at senescence dry weight losses ranging from 16 to 43% (Gosz et al. 1972). Depending on the method used (B-D) only 13-16% of the estimated net primary production of Filipendula was lost. It seems that other species litter disappeared more quickly than that of Filipendula. As a great part of the litter disappearance will be due to a breakdown into smaller fragments which were not collected at the samplings, more fragile and earlier dying species as Galium aparine and Vicia cracca may play some role. Moreover, as confirmed by several studies, leaf litter of different species decays at different rates and the chemical composition of the litter is probably of great importance. For example, Urtica dioica leaves died late in the season, but have almost vanished by November.

During one year, 60% of the aboveground litter of all species will disappear according to this study. Andersson (1970) measured a loss of 75% in a corresponding meadow in southwestern Sweden. The areas differ however, not only in climate and soil properties but especially in worm activity. The present investigation area contained very few earthworms.

In order to facilitate comparison of controls and Cd treatments, the litter loss was described by a negative exponential equation. In decomposition studies this equation has been frequently used, although other equations have sometimes proved to fit the experimental data better (Howard and Howard 1974, Jakubczyk 1976). Calculated losses from both the equations for old litter and litter in bags proved to agree well with those obtained in the field during the growing season.

For longer periods, however, the recorded disappearance rates would no longer be valid (Jakubczyk 1976). Weight losses in the current year's litter might still occur during the winter by leaching and by activity of decomposers. According to Bockock et al. (1960) the leaching appears to



be most important during the first weeks after leaf fall. In the old litter, however, weight losses due to leaching would be very small during the second winter of the litter, as easily leached substances have gone, leaving only those substances less easily attacked by decomposers. Besides the lower temperature, the almost water-soaked conditions of the soil and of the litter during the winter (ground water table at or near soil surface) may reduce the activities of decomposers due to shortage of oxygen. In consequence, the disappearance of old litter is probably negligible during the coldest months and the disappearance rate due to changed chemical composition of the litter as the decomposition progresses, is retarded. Therefore, the calculated 95% time for the initial weight of old litter to disappear is probably an underestimation.

Disappearance rate recorded for the litter in litter bags was about 35% lower than that of old litter. Differences in decay between unconfined and confined litter have been observed in several studies. Wiegert and Evans (1964) found that the rate of loss from litter bags was less than a quarter that from unconfined litter and Wallentinus (1973) found the rate to be about half that when unconfined. Both mesh size of the bags, which limits entry of larger invertebrates and changed microclimate, stratification and composition of the litter will contribute to these differences.

The difference may actually be greater than that measured in this study because different types of litter were used. The unconfined litter was old litter from which most of leachable and easily decomposable substances had already gone before the measurements began. Stems, leaf-stalks and litter of other species were also included. The confined litter was composed of leaf-blades of Filipendula alone, collected at senescence. The use of galvanized chicken wire over the litter bags was a mistake, because it gave an increased concentration of zinc in the litter. However, a

reduced disappearance rate due to this was probably negligible as a much higher concentration of zinc is needed to affect decomposers (Jordan and Lechevalier 1975).

Throughout the investigated season, roots were dying in the soil profile, but no seasonal increase of the belowground litter mass due to the addition of dead roots could be confirmed in the controls. These observations suggest that root litter disappears at the same rate as the roots die. Favourable moisture conditions in the soil and young roots (ca. 1 year old) may be the cause of the fast disappearance. It should be stressed, however, that the sampling procedure excluded smaller fragments of dead roots. In an Arrhenatherion meadow, the disappearance rate declined considerably after an initially rapid decomposition during the first 25-35 days. The time taken for complete decomposition of several years old roots would be more than two years. One year old roots decompose much faster (Jakubczyk 1976).

#### 7.4 Cadmium effects on above- and belowground biomass and net primary production

The effects of cadmium were clearly visible in the field, especially in plots, which had received the high Cd treatment, where many leaves of Filipendula were partly yellowing and curled early in the season. Chlorosis, beginning between the veins and resembling Fe deficiency, is the most generally noticed visual symptom of Cd toxicity. However, in many investigations this is found at significantly higher concentration of Cd in the leaf tissues than in the present study (Page et al. 1972, Dijkshoorn et al. 1974, Carlson et al. 1975, Patel et al. 1976, Mitchell and Fretz 1977, Kirkham 1978). By increased Cd concentration in tissue, curled leaves have also been noticed in soybean (*Glycine max*) (Boggess et al. 1978). Stunted growth with shortened stems, observed in Cd toxicity studies with cultivated plant species (John et al. 1972, Haghiri 1973, Lee et al. 1976, Williams and David 1977, Mahler et al. 1978) was not so evident in

the low as in the high Cd plots, where most Filipendula shoots were considerably shorter and less numerous per unit area than in the controls. The reduction in live shoot density could not be explained by an increased number of dead shoots during the season, so cadmium may have had an effect earlier in the year, before the harvesting period. In both the Cd treatments, the biomass of ripe seeds were strongly reduced, although the proportion of fertile shoots was unaffected or even increased. Evidently, cadmium may cause more flowering shoots but inhibit the formation of seeds. No observations were made between the harvest occasions in August and September, however, so earlier ripening and fall of the seeds cannot be ruled out.

The low Cd treatment caused only slight depression or even, in some cases, a slight stimulation of the growth of green parts. At the harvests in June-August, during which period the controls showed the greatest increase in biomass, the total biomass, including all species, was reduced by between 5-15%. Corresponding percentage decrease in the high Cd plots ranged from 26 to 46%. The biomass of Filipendula alone, was reduced to a lesser extent than was the total biomass, indicating that other species of the study area, of which some are annuals, tended to be more affected by cadmium.

Looking at the separate organs of Filipendula, the stem biomass was somewhat more affected than was that of the stem leaves for most of the season. Similar results were obtained for Chrysanthemum morifolium grown in nutrient solutions supplied with different concentrations of Cd. Although only a slight difference, there was at  $10^{-5}$  M Cd, a 43% decrease in biomass of stems and 37% of the leaf biomass, but the Cd concentration of the leaf tissues was almost 6 times greater than that of the stems (Patel et al. 1976). Such a great difference of Cd concentration was not found in the corresponding organs of Filipendula. With the exception of basal leaves, the Cd concentration in the



stems was almost the same as that in the stem leaves at the harvest in August (Balsberg 1980). Opposite results with stem and leaf biomasses were noticed in experiments with celery, soybean and bush-bean, however (Haghiri 1973, Collins et al. 1976, Wallace et al. 1977). This variety in results suggests that there may be not only a great difference in cadmium tolerance between species but also between organs of a species.

The weaker development and growth of stems and stem leaves, which was especially marked in the high Cd plots, probably gave the basal leaves a more favourable light climate, resulting in a slower yellowing and death of the earliest basal leaves and more vigorous regrowth of new ones later in the season.

On the whole, the belowground biomass was more affected by the Cd treatments than was the aboveground biomass. The effect was more evident later in the season than early in it and more marked if roots were considered alone. The formation and growth of roots was seriously disturbed and the mortality of old roots increased, especially that of roots in the upper part of the soil. In November, the biomass of roots in the 0-5 cm section, formed during the current season, was reduced by 36% and 80% in the low and high Cd treatments, respectively. At this time, the concentration of Cd in these roots, exposed to the high Cd treatment was 660 µg/g dry weight (Balsberg 1980). Bush-bean (*Phaseolus vulgaris*) roots with almost the same Cd concentration (656 µg/g) Wallace et al. (1977) obtained only a 27% biomass decrease, but the decrease in roots of the above mentioned chrysanthemum was about double that in bush-bean roots and independent of the root tissue Cd concentration (48 and 547 µg/g) (Patel et al. 1976).

Deeper in the soil profile, the Cd concentration of the soil was considerably lower and the inhibition of growing roots in the top of the soil, probably mostly horizontal, was

partly compensated by more vigorous growth of vertically growing roots.

In evaluating the effects on net primary production, the method of calculation appeared to be of great importance. Depending on the method used, the aboveground production of Filipendula ranged from a small increase to a decrease by as much as 6% in the low Cd plots when compared with controls. The estimated production of the high Cd plots was reduced by 23-32%.

The method of the calculation was even more important when estimating belowground production. The method in commonest use - taking the difference between seasonal maximum and minimum or initial biomass values as an estimation of production - proved misleading, when applied to the Cd treated plots. As in the control plots, both rhizomes and roots formed, but the seasonal change was totally masked when looking at the total. The separation of new organs from old ones, proved essential if accurate estimations were to be made. Although some overestimation, due to the production of rhizomes, could not be assessed, the total belowground production of the low and high Cd treated plots was reduced by 50% and 80%, respectively.

#### 7.5 Cadmium effects on above- and belowground litter

In the present work, the litter bags proved useful in confirming the effects of cadmium on litter disappearance. The disappearance rate in the high Cd plots was only 75% of that in the controls, while the rate in the low Cd plots was little different from that in controls. In an experiment with soil/litter microcosms from a Douglas fir forest in Oregon, Bond et al. (1976) obtained a stimulatory effect of oxygen consumption at lower concentrations of cadmium but a treatment with 10 µg/g cadmium showed an inhibition of 41%. However, during the 4 week experiment period, there

was no change in density of organisms. In a similar experiment with oak litter, evolution of carbon dioxide was reduced at higher concentrations of Cd, while a slight stimulation of decomposition was found at low Cd concentration. The possibility that the reduction of respiration rate resulted from osmotic effects could be rejected, however (Chaney et al. 1978).

The influence of cadmium was also evident on the disappearance of root litter. In the low Cd treatment, the percentage share of root litter increased in the second part of the season. Even in June, the proportion of root litter at high Cd was notably higher than in the controls. The litter seemed to be affected also in the 5-10 cm section.

Undoubtedly, in the long run, such a retardation in disappearance of litter would be serious because the release of nutrients, necessary for normal development of the plants in the ecosystem, would be delayed.

## 8 CONCLUSIONS

In this study of a tall herb meadow, the dominant Filipendula accounted for at least 82% of the plant biomass throughout the season. Maximum aboveground biomass of Filipendula ( $430 \text{ g/m}^2$ ) and of all species ( $586 \text{ g/m}^2$ ) was reached in August in the controls. As in most other plant communities with dominant perennial species, the main part of the biomass, 62% or more, was below ground. For most of the season about half of this biomass was in rhizomes of Filipendula, which were concentrated (as were roots) in the upper 5 cm of the soil. The simple structure of the plant community with only a few species, allowed separation of the roots of the dominant species from those of other species. Although time consuming, a further separation into current and previous year's roots of Filipendula, revealed a yearly turnover of these roots of about 75% in the controls, a value which is higher than



has been reported from most other root studies.

The main results of this study, annual net primary production, litter disappearance and the amount of litter and belowground organs at the end of the season are summarized for both the controls and the Cd treatments in Fig. 13. The methods for determining net primary production particularly that below ground gave different results and this complicated the evaluation of the effects of cadmium.

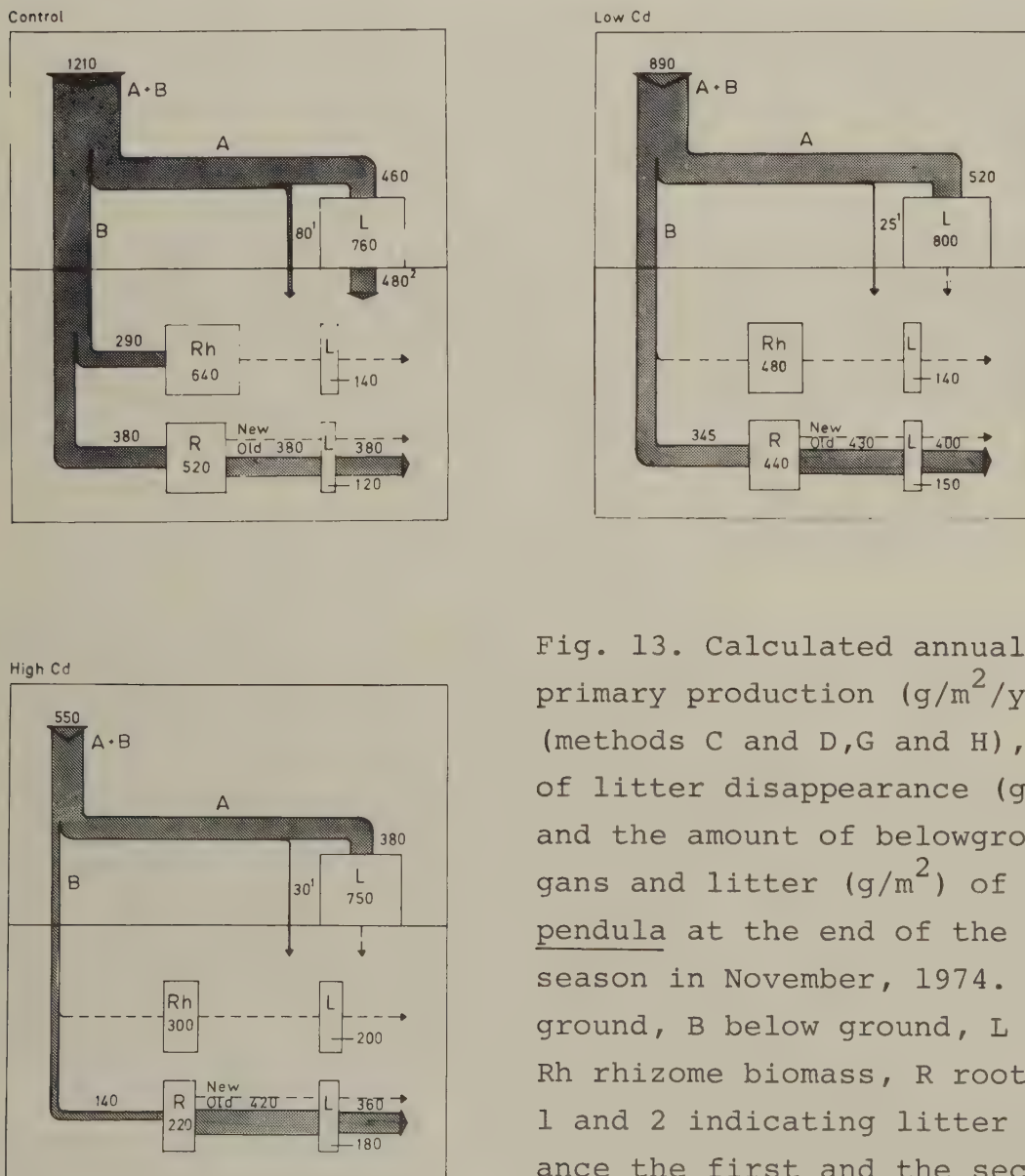


Fig. 13. Calculated annual net primary production (g/m<sup>2</sup>/yr) (methods C and D, G and H), rate of litter disappearance (g/m<sup>2</sup>/yr) and the amount of belowground organs and litter (g/m<sup>2</sup>) of *Fili-pendula* at the end of the growing season in November, 1974. A above ground, B below ground, L litter, Rh rhizome biomass, R root biomass, 1 and 2 indicating litter disappearance the first and the second season, respectively, --- not calculated.

In conclusion it is clear that cadmium at concentrations which may be reached locally in polluted areas had a marked effect in this ecosystem. Visual symptoms such as chlorosis, curled leaves, stunted shoots and reduced shoot density developed early in the season at the high Cd treatments. Although the effects of cadmium on aboveground biomass and production were evident only at the high Cd concentration, the belowground organs were strongly affected at low Cd concentration too, showing lowered production and increased mortality.

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STUDIES IN A FILIPENDULA ULMARIA L. MEADOW ECOSYSTEM  
AND THE EFFECTS OF CADMIUM II. CONCENTRATION AND  
DISTRIBUTION OF CADMIUM IN PLANT BIOMASS AND SOIL

Anna-Maj Balsberg





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## 1 INTRODUCTION

During the last decade the heavy metal cadmium and its toxic effects on various organisms have attracted much attention. Even at low concentration levels, cadmium is regarded as very harmful to man, a fact that might have had the result that cadmium studies of plants have been mainly limited to agricultural and vegetable plant species. Although levels of cadmium in the environment have increased, information about wild plant species, especially under natural conditions is surprisingly scanty.

This paper reports a continuation of a study in a Filipendula ulmaria meadow ecosystem, which has been exposed to added cadmium at two concentration levels. For estimations of biomass, production and litter disappearance rate, and a detailed description of the area, see Balsberg (1980).

The meadow-sweet (Filipendula ulmaria L.) (hereafter named Filipendula only) is the totally dominating species of the area, while other species such as Vicia cracca L., Galium aparine L., Galeopsis tetrahit L. and Urtica dioica L. make up the vegetation to a minor extent. The area is almost level and has a high ground water table for most of the year. The soil is a moist peaty mull with a surface pH about neutral. Other soil characteristics of importance to this study are shown in table 1.

The primary aims of this study were to describe the uptake of cadmium by Filipendula in relation to the cadmium content of the soil, and the seasonal distribution of cadmium in various plant components.

| Soil depth<br>(cm) | Clay<br>(% dry weight) | Organic<br>matter<br>(% dry weight) | pH<br>(soil:H <sub>2</sub> O<br>weight<br>prop.1:2) | CEC<br>per unit<br>dry weight<br>(meq/100 g) | Metal ion<br>saturation<br>(%) | Concentration of extractable<br>cation per unit dry weight |                                                   |
|--------------------|------------------------|-------------------------------------|-----------------------------------------------------|----------------------------------------------|--------------------------------|------------------------------------------------------------|---------------------------------------------------|
|                    |                        |                                     |                                                     |                                              |                                | Ca<br>in neutral<br>1 M NH <sub>4</sub> OAC<br>(mg/g)      | Cd<br>in 0.05 M<br>Na <sub>2</sub> EDTA<br>(ug/g) |
| 0-5                | 15.6                   | 67.3                                | 6.8                                                 | 102                                          | 90.4                           | 16.3                                                       | 1.15                                              |
| 5-10               | 13.6                   | 57.8                                | 6.5                                                 | 89                                           | 87.0                           | 14.3                                                       | 0.90                                              |
| 10-20              | 18.4                   | 41.2                                | 6.1                                                 | 62                                           | 81.4                           | 9.1                                                        | 0.66                                              |
| 20-30              | 19.0                   | 38.4                                | 6.2                                                 | 56                                           | 77.3                           | 7.8                                                        | 0.55                                              |
| 30-40              | 12.9                   | 56.0                                | 6.3                                                 | 74                                           | 77.1                           | 10.1                                                       | 0.62                                              |
| 40-50              | 12.8                   | 65.7                                | 6.4                                                 | 81                                           | 77.0                           | 10.7                                                       | 0.57                                              |

Tab. 1. Physical and chemical properties of the soil in August, 1973.



## 2 METHODS

### 2.1 Field procedure and sampling

Field procedure and sampling are described more in detail in the previous report (Balsberg, 1980). Square plots ( $1\text{ m}^2$ ) were distributed regularly in a network within the study area. The distance between adjacent plots' borders was 1 m. Experimental plots were randomly exposed to two levels of cadmium. The amount of cadmium added was calculated to give 25  $\mu\text{g/g}$  and 250  $\mu\text{g/g}$  dry weight of the soil in the top 20 cm. In the following the untreated and cadmium treated plots are named control, low Cd and high Cd, respectively.

The Cd treatments were performed in November 1973, the year before sampling. After temporarily removing most of the litter, each experimental plot was sprinkled with cadmium solution ( $\text{CdCl}_2 + \text{CdAc}_2$ , prop 1:1). A laboratory test had indicated that the pH of the soil did not change with this mixture and proportion of the salts. The control plots were supplied with water only.

All samplings were undertaken during 1974, on six occasions, the first on 20-21 April and the final one on 10-11 November. On each occasion, samplings were performed in five randomized plots of each of the control, low and high Cd treatments. Aboveground plant matter including litter was collected within an area of  $0.75 \times 0.75\text{ m}$  of the plot. Thereafter two soil cores were taken to a depth of 20 cm in each plot using a stainless steel cylinder with an inner diameter of 20 cm.

### 2.2 Sample preparation and chemical analysis

To avoid contamination, the material from the different plots was treated separately. The aboveground living material of Filipendula was fractioned into as many as

17 various components. The fresh litter of 1974 was separated from that of the previous year (old litter). The soil cores were sliced into three sections (0-5 cm, 5-10 cm and 10-20 cm). Using a pair of tweezers, the below-ground organs, including dead ones, were separated from the soil. A separation was also made between old roots, mainly formed in the year before, and new roots formed during the current season. Soil particles were removed by rapidly rinsing each fraction of the belowground organs with deionized water, thereafter all plant material was dried at 85° C to a constant weight. The soil samples were deepfrozen.

After determination of dry weight, a part of each plant fraction from the five replicates was ground and mixed to form a composite sample. From this composite sample, duplicates were taken for total analysis of cadmium. After digestion with  $\text{HNO}_3 + \text{HClO}_4$  (vol. prop. 4:1) cadmium was determined by flame atomic absorption spectrophotometry. For each soil section, a composite soil sample was formed in the same manner as that of the plant material and carefully mixed. Twenty-five gram of the fresh soil sample was extracted for 1 h with 50 ml 0.05 M  $\text{Na}_2\text{EDTA}$ . By atomic absorption spectrophotometry, cadmium was determined in duplicates from each composite sample.

### 2.3 Calculations and statistical treatment

All values presented of cadmium concentration in soil and plant material are averages of duplicates and are given on a dry weight basis. Statistical calculations (t-tests) were performed on the entire material.

### 3 RESULTS

#### 3.1 Cadmium concentration and distribution in soil

It was not possible to observe any variation of Cd concentration related to season in any soil section. In the controls, the concentration averaged 1.6  $\mu\text{g/g}$  in the 0-5 cm section and 0.80  $\mu\text{g/g}$  in the lowest measured section (10-20 cm) (Tab. 2). A markedly higher Cd concentration was measured in the Cd treated soils, especially in the uppermost section, but the concentration decreased rapidly with depth.

When comparing the percentage distribution of the amount of Cd in the soil profile, there was an increase with soil depth in the controls (from an average of 21.6% in the 0-5 cm section to 47.7% in the 10-20 cm section). In contrast, the greatest amount in the Cd treated soils, on average almost 80%, was retained in the surface soil section and only 5-6% in the 10-20 cm section.

| Soil depth<br>(cm) | Cd concentration<br>( $\mu\text{g/g}$ dry weight) |         |         | Distribution<br>(%) |         |         |
|--------------------|---------------------------------------------------|---------|---------|---------------------|---------|---------|
|                    | Minimum                                           | Maximum | Average | Minimum             | Maximum | Average |
| <u>Control</u>     |                                                   |         |         |                     |         |         |
| 0- 5               | 1.0                                               | 2.0     | 1.6     | 17.0                | 28.1    | 21.6    |
| 5-10               | 1.1                                               | 1.4     | 1.2     | 25.6                | 34.1    | 30.7    |
| 10-20              | 0.57                                              | 1.2     | 0.84    | 38.6                | 54.2    | 47.7    |
| <u>Low Cd</u>      |                                                   |         |         |                     |         |         |
| 0- 5               | 79                                                | 140     | 110     | 73.4                | 83.8    | 79.2    |
| 5-10               | 4.8                                               | 16      | 11      | 9.4                 | 18.6    | 14.5    |
| 10-20              | 1.5                                               | 2.8     | 1.9     | 3.8                 | 9.0     | 6.3     |
| <u>High Cd</u>     |                                                   |         |         |                     |         |         |
| 0- 5               | 800                                               | 1400    | 1100    | 71.6                | 82.4    | 78.0    |
| 5-10               | 98                                                | 140     | 130     | 13.4                | 22.8    | 16.9    |
| 10-20              | 14                                                | 26      | 16      | 3.4                 | 8.3     | 5.1     |

Tab. 2. Minimum, maximum and average values for concentration and percentage distribution of cadmium in the soil profile (in percentage of the total amount in the soil, 0-20 cm) during the study season.

### 3.2 Distribution of cadmium between plant material and soil

As a mean of all sampling occasions, almost 90% of the total Cd added to the plots in November, 1973 was found from measurements of biomass, litter and soil components in 1974. Throughout the studied season, most of the Cd was found in the soil (Tab. 3). The percentage share of Cd was somewhat higher in the control soils (on average 90%) than in the low and high Cd treated soils (78% and

|                     | 21/4 | 9/6  | 7/7  | 4/8  | 15/9 | 11/11 |
|---------------------|------|------|------|------|------|-------|
| <u>Control</u>      |      |      |      |      |      |       |
| Above ground        |      |      |      |      |      |       |
| Biomass+new litter  | 0.08 | 1.2  | 1.0  | 1.1  | 0.9  | 1.4   |
| Old litter          | 1.5  | 2.4  | 1.6  | 1.1  | 0.6  | 1.0   |
| Below ground        |      |      |      |      |      |       |
| Biomass+litter      | 6.3  | 11.6 | 6.3  | 6.9  | 5.1  | 7.7   |
| Soil 0-20 cm        | 92.1 | 84.8 | 91.1 | 90.9 | 93.3 | 89.9  |
| <u>Low Cd</u>       |      |      |      |      |      |       |
| Above ground        |      |      |      |      |      |       |
| Biomass+ new litter | 0.14 | 0.6  | 0.5  | 0.5  | 0.8  | 1.2   |
| Old litter          | 22.8 | 22.4 | 10.2 | 11.5 | 6.6  | 5.3   |
| Below ground        |      |      |      |      |      |       |
| Biomass+litter      | 8.5  | 7.4  | 7.1  | 6.6  | 7.9  | 11.7  |
| Soil 0-20 cm        | 68.6 | 69.6 | 82.2 | 81.4 | 84.7 | 81.8  |
| <u>High Cd</u>      |      |      |      |      |      |       |
| Above ground        |      |      |      |      |      |       |
| Biomass+new litter  | 0.04 | 0.2  | 0.5  | 0.7  | 0.4  | 0.6   |
| Old litter          | 8.0  | 8.1  | 10.5 | 6.7  | 4.4  | 4.2   |
| Below ground        |      |      |      |      |      |       |
| Biomass+litter      | 4.4  | 3.8  | 6.7  | 4.5  | 4.3  | 4.0   |
| Soil 0-20 cm        | 87.6 | 87.9 | 82.3 | 88.2 | 90.9 | 91.2  |

Tab. 3. Percentage distribution of cadmium between biomass, litter and soil during the study season.



88%, respectively). With some variation between sampling occasions, on average 7.3% of total Cd in the controls was found in the belowground plant parts but only 0.9% in the aboveground ones, including litter formed during the current season. In the low and high Cd treated plots, the corresponding value for belowground parts was 8.2% and 4.6% and for aboveground ones 0.6% and 0.4%, respectively. Old litter contained a higher percentage of Cd during the first half of the season than later on. This was especially marked in the low Cd treatments, where 22.8% of the total Cd was recovered in old litter in April but only 5.3% in November.

### 3.3 Ratios of cadmium concentration in various plant components for control and Cd treatments

Cadmium concentration in plant tissue of both above- and belowground organs increased markedly with increasing soil Cd concentration. The greatest concentration difference from the control was obtained for rhizomes and roots in the 0-5 cm soil section (Tab. 4). The low Cd treatment, increased the soil Cd concentration almost 70 times (Tab. 2) and that of rhizomes and roots 50 and 60 times respectively. The difference in the soil Cd concentration between the two Cd treatments was about 10-fold, but only 7- and 3-fold for rhizomes and roots, respectively. With increasing soil depth, the difference in root Cd concentration between control and Cd treatments decreased very markedly.

In aboveground shoots, the ratio of Cd in stem leaves was, on average, 1:7:35 (control:low Cd:high Cd), but the difference was greater for stems and basal leaves. The relatively high values for the basal leaves could be due to the fact the Cd addition in 1973 was performed by sprinkling the plots with a Cd solution. At that time, primordial shoots of Filipendula had developed so the earliest leaves of the plant might have absorbed some Cd.

Control:Low Cd:High Cd

Above ground

|              |   |   |    |   |     |
|--------------|---|---|----|---|-----|
| Stem leaves  | 1 | : | 7  | : | 35  |
| Stems        | 1 | : | 9  | : | 40  |
| Basal leaves | 1 | : | 12 | : | 66  |
| Leaf litter  | 1 | : | 15 | : | 140 |

Below ground

|                 |   |   |    |   |     |
|-----------------|---|---|----|---|-----|
| Rhizomes        | 1 | : | 48 | : | 341 |
| Roots           |   |   |    |   |     |
| (depth) 0- 5 cm | 1 | : | 59 | : | 184 |
| 5-10 cm         | 1 | : | 8  | : | 38  |
| 10-20 cm        | 1 | : | 4  | : | 18  |
| Dead rhizomes   | 1 | : | 24 | : | 288 |
| Dead roots      |   |   |    |   |     |
| (depth) 0- 5 cm | 1 | : | 41 | : | 456 |
| 5-10 cm         | 1 | : | 5  | : | 52  |
| 10-20 cm        | 1 | : | 2  | : | 18  |

Tab. 4. Ratios of cadmium concentration in various plant components for control and Cd treatments; means of all sampling occasions.

This was also apparent from the current year's leaf litter values.

Throughout the season, the difference in concentration of Cd in the plant components between the Cd treatments was fairly constant. With the exception of rhizomes, it was 3-5 fold for the living plant parts and 9-11 fold for dead ones.

### 3.4 Cadmium concentration in plants

The plant Cd concentration in plants was measured in all the separate organs of Filipendula, which were sampled during 1974. Any obvious tissue concentration changes related to season could not be detected, only in old roots was there a tendency towards a decreased concentration as the season progressed. In early August, most studied organs of Filipendula developed at the same time.

The concentration values at that time (see Fig. 1) may serve as a basis for the following presentation of observations complemented with statistical tests performed on the entire material of the season.

Throughout the studied season, the difference in Cd concentration between above- and belowground organs was great. It was apparent that the Cd concentration in the roots was always the highest and generally several times higher than that of corresponding aboveground shoots of the plant. In the control plots the Cd concentration in roots growing in the surface soil section was, on average,

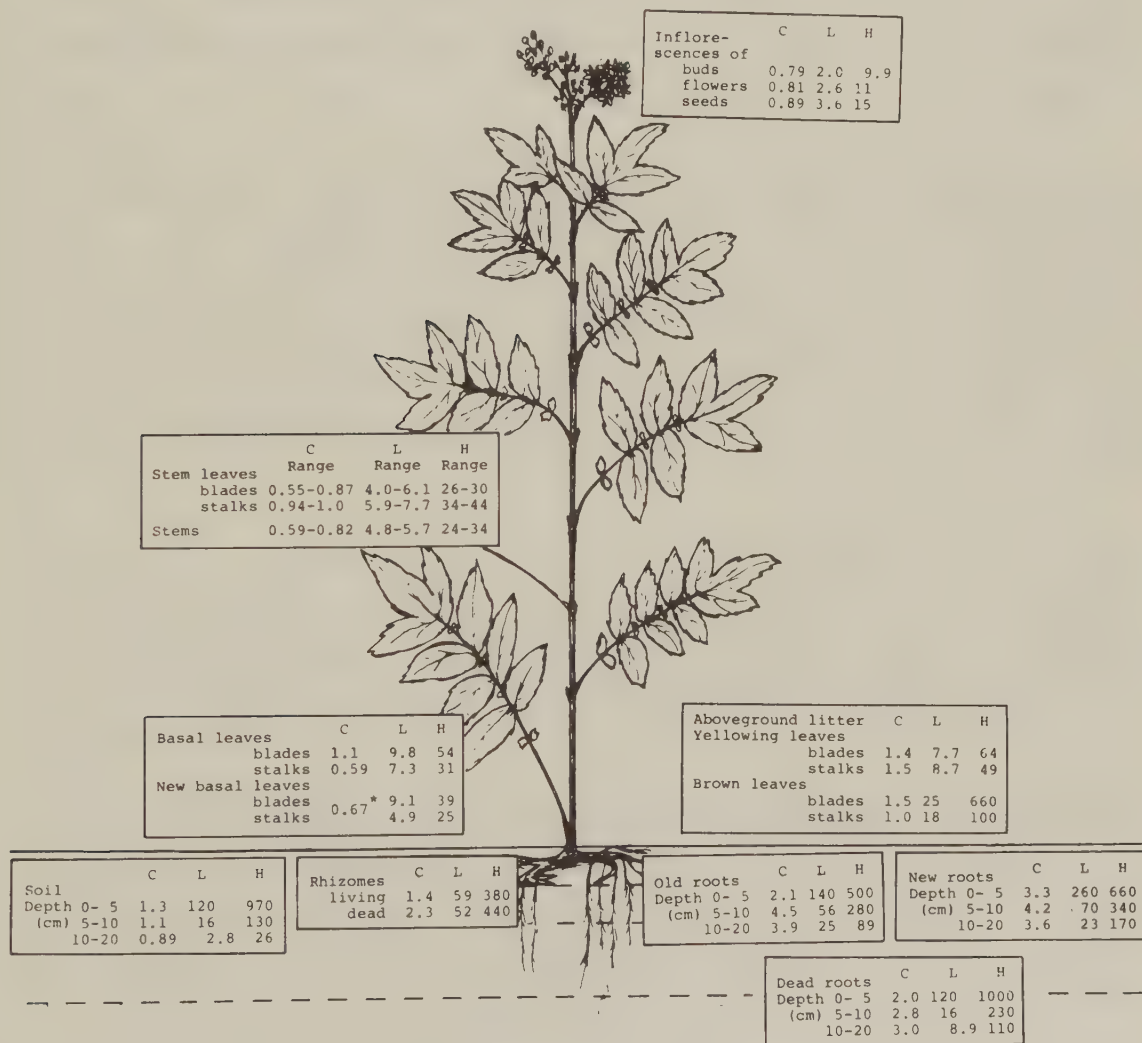


Fig. 1. Concentration of cadmium ( $\mu\text{g/g}$  dry weight) in various organs of *Filipendula* and in soil, on 4 August 1974 (C control, L low Cd, H high Cd).

less than that in roots growing deeper in the soil. An inverse relationship was found for roots in the Cd treatments, i.e. the highest Cd concentration was obtained in the surface roots, whereas it was significantly lower in the roots below. Although not fully clear from the August measurements (values for the control roots were generally higher at the other measurements during the season), new roots contained more Cd than old ones. However, the difference was most significant ( $p \leq 0.01$ ) for roots from the control and low Cd treatment and was greater for roots growing in the 5-20 cm soil sections than for those growing in the surface section. Depending on soil depth, the Cd concentration of new roots was, as an average of the season, 1.3 to 1.9 times the concentration of old ones.

A significant difference could also be observed between the concentration of living rhizomes and roots, of which the roots contained most Cd ( $p \leq 0.001$ ). As with old and new roots, the greatest difference was obtained in the control and low Cd treatment (on an average of the season about a factor of 3), while it averaged 1.5 in the high Cd treatment.

Dead roots and dead rhizomes generally had less Cd than corresponding living ones, but the reverse applied to control rhizomes, and both rhizomes and roots in the 0-5 cm soil section of the high Cd treated plots.

Following the upward transport of Cd in aboveground parts, the highest Cd concentration was obtained in the lowest leaves of the plant. The basal leaves, attached to the stem just above ground level, contained more Cd than the stem leaves on all occasions, but the difference was greater in the beginning of the season than later on. However, as mentioned above, part of these increased concentration values for the basal leaves and for the current litter of the Cd treatments may be



largely explained by the method used when applying the Cd solution. In both stem and stem leaves, the concentration decreased usually gradually towards the top of the plant. So, depending on the attachment height on the stem, the leaf-blade and leaf-stalk concentrations of the controls in August, ranged from 0.55-0.87  $\mu\text{g Cd/g}$  and 0.94-1.0  $\mu\text{g Cd/g}$ , respectively. The same Cd concentration pattern was observed in plants from the Cd treatments.

Leaf-stalks contained more Cd than corresponding leaf-blades, but the difference was more obvious in leaves of the Cd treatments ( $p \leq 0.001$ ) than in those of the control ( $p \leq 0.05$ ). Conversely, leaf-stalks of basal leaves contained less Cd than corresponding leaf-blades. This was also true for newly developed basal leaves, collected for the first time in August. Statistically significant only in the control material ( $p \leq 0.05$ ) the leaf-stalks were somewhat richer in Cd than stems. Although fairly similar to that of the stem leaves in the controls, the lowest Cd concentration for the Cd treatment plants was obtained in the reproductive organs.

### 3.5 Index of cadmium concentration in plants

In order to compare the ability of plants grown in soil with different Cd concentration, to take up Cd in various organs, index values were calculated for the individual organs. For the belowground organs, this index value is the ratio of the Cd concentration in an organ of a special soil section to the Cd concentration in the soil section. Cadmium concentration of aboveground organs could not be ascribed to a special soil Cd concentration in the same manner as the belowground organs as it varied with soil depth. Thus Cd concentration index for aboveground organs is the ratio of Cd concentration in an organ to that in rhizomes.

The concentration index was below 1.0 for rhizomes at all Cd levels, but was more than 15 for new roots (Fig.2). With increased soil depth, the index value for roots increased very markedly. Thus it was significantly higher ( $p \leq 0.001$ ) for roots of the 5-10 cm and 10-20 cm soil sections than for those of the 0-5 cm section. When comparing new roots to old roots the difference between index values was ranging from 1.2 to 2.2 times. The index value generally decreased with increased Cd treatment. For the belowground organs, the difference between the index values of the high Cd treatment and those of the control and low Cd treatment was highly significant ( $p \leq 0.001$ ). The index values for aboveground organs, however, showed relatively, an even greater difference, which was significant at  $p \leq 0.001$  between the control and both the Cd treatments. For all aboveground organs of the control, the index value was at or above 0.6 but just about or below 0.1 for those of the Cd treatments.

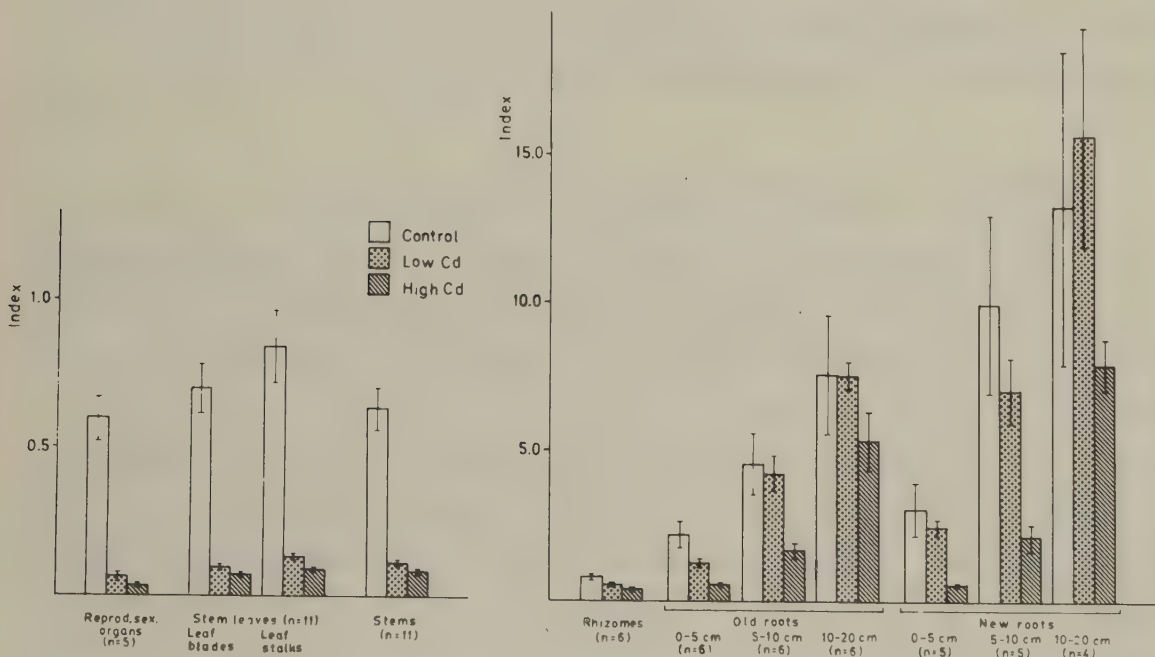


Fig. 2. Cadmium concentration index in various organs of *Filipendula* during the study season. Vertical bars are representing standard error of mean.

### 3.6 Content and seasonal distribution of cadmium in biomass

Below- and aboveground biomass was reduced to varying extent by the addition of Cd. This is described in detail in Balsberg (1980). The ratio of aboveground biomass of low Cd treatment to that of the control was fairly constant during the season, ranging from 0.9 to 1.1. Corresponding ratios for high Cd treatment were 0.6-0.7. The Cd content in biomass from the Cd treatments, however, was several times larger than that of the control. With a tendency to decrease during the season, the biomass Cd of the low and high Cd treatments in June-September was 7-13 times and 27-44 times higher than that of control, respectively.

From a somewhat larger belowground biomass than the control in April, the low and high Cd treatment biomass decreased by 16% and 44%, respectively, as an average of the remaining part of the season. The biomass Cd increased by 25 and 75 times the Cd concentration of the control biomass. The seasonal variation in the ratios formed by belowground biomass Cd from the Cd treatments and from the control followed the seasonal variation of biomass.

The seasonal distribution of Cd in the plant biomass was calculated as the percentage of the amount of Cd, which was taken up in each plant organ to that in total biomass (Fig. 3 A-B). Compared to the seasonal distribution of plant organ biomass (Fig. 3 A) an exceptionally high percentage of total Cd in biomass was found in the belowground organs, especially the roots (Fig. 3 B). From June to September, when aboveground biomass made up 23 to 34% of total biomass of the controls, only about 10% of the total biomass Cd was bound in this fraction. For the Cd treatments a still lower percentage was found.

The percentage share of Cd in rhizome biomass increased markedly with increased Cd level. Inversely, the amount



of Cd connected to the root biomass decreased. Most root biomass of the controls was found in the surface soil section. Root biomass Cd, however, was fairly equally distributed among the sections. With increased Cd treatment, the difference in distribution of root biomass between the sections tended to be more equalized, while the amount of total root Cd appeared to be more restricted to the uppermost 5 cm of the soil. In the low Cd treatment more than 60% of the total Cd was bound in the root biomass, and of this amount, more than 80% on average, in the 0-5 cm soil section.

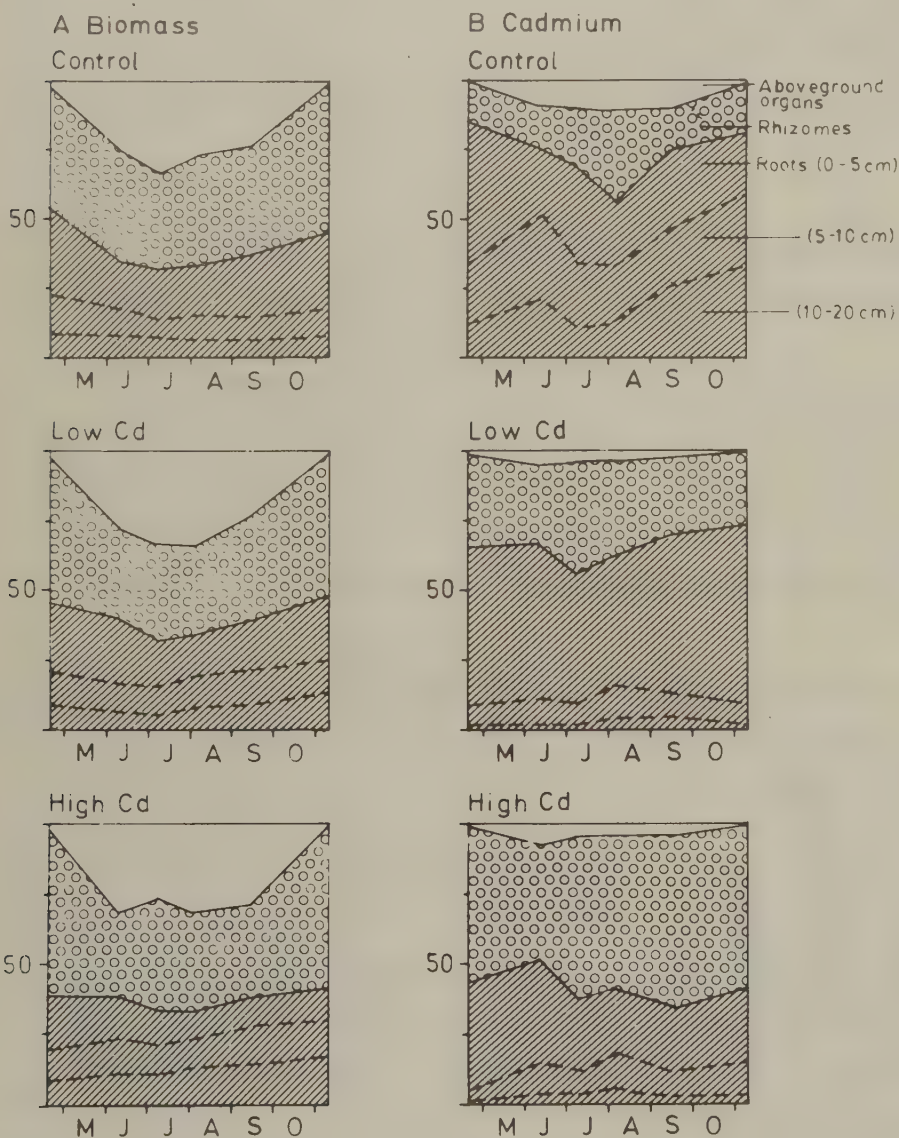


Fig. 3. Distribution of various plant organ biomasses as percentages of the total biomass of *Filipendula* (A) and the distribution of Cd amount in these organs as percentages of the total amount of Cd in the biomass (B).



## 4 DISCUSSION

It is evident from several studies that physical and chemical properties of a soil may have a great influence on movement of Cd in the soil and on plant availability. By an ion exchange mechanism, soil organic matter is known to bind Cd ions to a considerable extent. Movement of Cd in soil and plant uptake is reversely related to cation exchange capacity, pH and calcium content, etc. (e.g. John 1971, Andersson and Nilsson 1974, Haghiri 1974, Miller et al. 1976, Garcia-Miragaya and Page 1978). High values of these soil factors characterized the soil in this study. Thus, added Cd was mainly retained in the surface soil and a further movement down the profile seemed to be very slow. The 10-fold difference between the Cd treatments gave almost the same difference in the soil Cd concentration of the separate soil sections, indicating that the movement of Cd was proportional to the amounts supplied and even in the high Cd treatment, the adsorption maximum of the soil did not seem to be attained. Furthermore, the fluctuating ground water table, high during most of the season ought to make not only vertical but also horizontal movement of Cd easier. Compared to the measurement in 1973, the average soil Cd concentration of the controls for the season, 1974, was somewhat higher. Although small, a transport from Cd treated plots could not be excluded. On the other hand, the soil Cd values measured in 1974 showed a fairly great variation between the sampling occasions and the measurement from only one sampling occasion in 1973 was perhaps not quite representative. In any case, under the present conditions with a pH about neutral, the solubility of Cd is apparently small and most Cd may be effectively bound to soil components.

In this and other studies, most soil Cd has proved to be in an exchangeable form but the uptake in plant bio-

mass was low in relation to total amount of Cd in the soil. Less than 1% of the total Cd in the system was found in aboveground biomass and current litter but 4-8% in that below ground. Values in the same range have been reported from an undisturbed urban dune-marsh ecosystem, where plant biomass and litter of the dune ecosystem contained 2 to 3% of the total Cd burden and that of the wetlands about 2-5% (Parker et al. 1978). In two heather ecosystems (*Calluna* and *Erica*), the amount of Cd in belowground biomass and litter accounted for 2.0% and 4.3% of the total Cd in biomass, litter and soil, respectively, but the amount was below 0.5% in aboveground biomass (Tyler et al. 1973).

The distribution of the amount of Cd in the separate plant organs was not in similar proportion to the biomass of the organs, nor to the various soil Cd levels. At most about 10% of the total amount of Cd in the biomass of the controls was found in the aboveground parts. The value was still lower in the Cd treatments. A remarkably large share of the total biomass Cd of the controls was bound in the root fraction. With increasing soil Cd concentration, this share decreased markedly. In the plots with high Cd treatment, the rhizome fraction contained as much or even more Cd than the roots throughout the season. However, uptake and retention of Cd in roots will depend on the root morphology. Roots of 17 agricultural and vegetable plant species grown in nutrient solutions with Cd added, retained more than 65% of the total uptake. Comparably, retention in the fibrous roots of parsnip reached ca 90% (Jarvis et al. 1976). Similar values, 86% to more than 97% was obtained in grass species (Kabata-Pendias and Bolibrzuch 1976, Jarvis and Jones 1978). Naturally, the results obtained in this study depend both on the variation in biomass and on root Cd concentration. It is well known from other studies that roots generally contain more Cd than aerial parts of the plant.

Depending on the treatment level, the root Cd concentration exceeded, on average, 8-13 times the concentration in aboveground shoots. Furthermore, the Cd concentration was significantly higher in new roots than in old ones, probably due to the fact that lateral roots were more numerous on new roots, giving a greater total root surface. When comparing Cd concentrations in different root size fractions from various species, the finest roots tended to accumulate more Cd than the thicker ones (Balsberg 1971, Van Hook et al. 1977).

Different mechanisms are assumed to be involved in Cd uptake by roots. In short term experiments, uptake is regarded as predominantly an exchange process (Cutler and Rains 1974, Jarvis et al. 1976). The primary mechanism in both living and dead tissue appears to be a nonmetabolic binding of the metal to binding sites on the cell walls. The cell walls have a high capacity to bind Cd, so most Cd is retained in this cell fraction, preventing entry into the cell. Toxic effects may arise when the capacity of the cell walls to immobilize Cd is exceeded (Cutler and Rains 1974, Dabin et al. 1978). The Cd immobilization of cell walls might be responsible for the fairly high Cd concentration found in roots in relation to the concentration of the metal in the soil. Generally several times greater in relation to the growth medium than in the present study, such a Cd accumulation by roots has been obtained in most other studies too, including both cultures in soil and nutrient solutions. (e.g. Page et al. 1972, Collins et al. 1976). The experimental period of this study, however, was of a longer duration than those mentioned above. Thus, soil Cd might be effectively bound to soil components, making plant uptake more difficult. With increasing soil Cd level, the concentration index for roots decreased and in the high Cd treatment was significantly lower than in the control. This result indicates that a maximum uptake level was reached

even at a lower soil Cd level and the binding sites on the cell walls might be occupied. Probably as a consequence of this, the Cd concentration in rhizomes of the high Cd treatment attained proportionately a higher value in relation to that of control rhizomes. Another contributing factor facilitating Cd movement could be root damage, which has been observed in tomato plants at higher Cd levels (Turner 1973).

The Cd movement from roots to rhizomes and further on to aboveground organs, seemed to be restricted by the roots of the control, while the greatest 'barrier' for Cd movement in the Cd treated plants seemed to be from rhizomes to stems. With regard to the three Cd levels studied, the Cd concentration of various plant organs decreased in the following order: new roots > old roots > rhizomes > stem leaf-stalkes > stems  $\simeq$  stem leaf-blades > sexual reproductive organs. Similar results were obtained by John (1973), Haghiri (1973), Lönsjö (1977), Dabin et al. (1978) and Strickland et al. (1979), although not all organs were studied simultaneously by these authors.

## 5 CONCLUSIONS

It might be concluded under the present soil conditions, that Cd was effectively bound to soil components and movement of Cd added to the soil appeared to be very slow during the investigated season. Most of the Cd in the plant-soil system was retained in the soil and less than 10% was found in plant biomass. Root Cd concentration exceeded several times that in soil, but the concentration in various organs generally decreased gradually towards the top of the plant. Plant Cd concentration in relation to soil Cd content, and Cd content and distribution in the biomass were dependent on the level of soil Cd and differed markedly between the control and the Cd treatments.



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